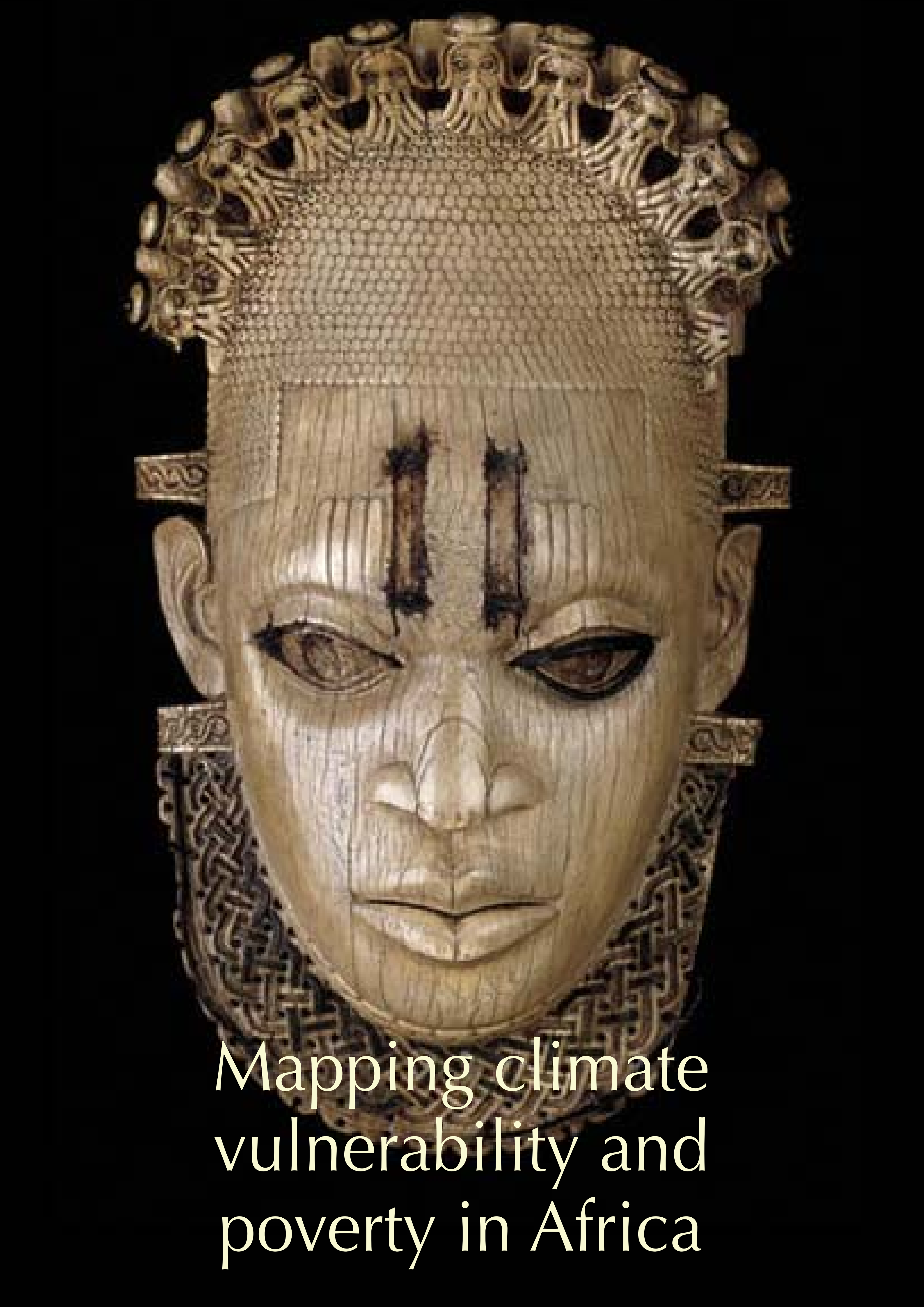

Mapping climate vulnerability and poverty in Africa

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Report to the Department for International Development

submitted by

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Executive Summary

The world's climate is continuing to change at rates that are projected to be unprecedented in recent human history. Some models are now indicating that the temperature increases to 2100 may be larger than previously estimated in 2001. The impacts of climate change are likely to be considerable in tropical regions. Developing countries are generally considered more vulnerable to the effects of climate change than more developed countries, largely attributed to a low capacity to adapt in the developing world. Of the developing countries, many in Africa are seen as being the most vulnerable to climate variability and change. High levels of vulnerability and low adaptive capacity in the developing world have been linked to factors such as a high reliance on natural resources, limited ability to adapt financially and institutionally, low per capita GDP and high poverty, and a lack of safety nets. The challenges for development are considerable, not least because the impacts are complex and highly uncertain.

The overall aims of DFID's new research programme on climate change and development in sub-Saharan Africa are to improve the ability of poor people to be more resilient to current climate variability as well as to the risks associated with longer-term climate change. The programme is designed to address the knowledge implications of interacting and multiple stresses, such as HIV/AIDS and climate change, on the vulnerability of the poor, and it will concentrate on approaches that work where government structures are weak. To help identify where to locate specific research activities and where to put in place uptake pathways for research outputs, information is required that relates projected climate change with vulnerability data. ILRI undertook some exploratory vulnerability mapping for the continent in late 2005 and early 2006, building on some livestock poverty mapping work carried out in 2002. The work described here is a small piece of a larger activity that involved the commissioning of several studies on climate change and the identification of the critical researchable issues related to development.

A project inception meeting was held with research collaborators, to discuss analytical approaches and assess data availability. Over the succeeding few months, data were assembled and analysis undertaken. This involved the downscaling of outputs from several coupled Atmosphere-Ocean General Circulation Models (GCMs) for four different scenarios of the future, and possible changes in lengths of the growing period were estimated for Africa to 2050 for several different combinations of GCM and scenario (we used the SRES scenarios of the IPCC). Results are presented on the basis of agricultural system types by country, using a systems classification as a proxy for the livelihood options available to natural resource users. From this, we identified areas that appear to be particularly prone to climate change impacts. These include arid-semiarid rangeland and the drier mixed systems across broad swathes of the continent, particularly in southern Africa and the Sahel, and coastal systems in eastern Africa.

The next stage was to consider the biophysical and social vulnerability of these and other areas. To characterise sub-Saharan Africa in terms of vulnerability, on the same country-by-system basis as was done for the climate change impacts, a set of proxy indicators developed at the workshop was pragmatically assessed in relation to data sources, while being guided by the experiences of others in the area. A final set of fourteen indicators was used; three are associated with natural capital, one with physical capital, two with social capital, six with human capital, and two with financial capital. We carried out statistical analysis and reduced this set of fourteen proxy indicators to four components, which were then used to construct an "overall" indicator of vulnerability, and systems-by-countries were then classified in quartiles. These results were then qualitatively combined with the climate change hotspot analysis. The results should be treated as indicative only, and we would caution strongly against their over-interpretation, particularly because the uncertainty associated with them is not yet known. Results do indicate, however, that many vulnerable regions are likely to be adversely affected in sub-Saharan Africa. These include the mixed arid-semiarid systems in the Sahel, arid-semiarid rangeland systems in parts of eastern Africa, the systems in the Great Lakes region of eastern Africa, the coastal regions of eastern Africa, and many of the drier zones of southern Africa.

There are several limitations to the analysis and to the availability of data for such work. For the future, considerable emphasis needs to be placed on collaborative efforts to collect and greatly improve the store of baseline information, on understanding very well the needs of potential users, on developing more flexible and generic frameworks for assessing vulnerability, taking advantage of the experiences of others in vulnerability assessment work in developing-country contexts through south-south collaboration, and on incorporating scenario analysis into the impact assessment framework.

The project also involved a study of the potential uses of information concerning climate variability and climate change for effective decision-making. A small survey of potential users was carried out. Findings of the survey confirm the results of other scoping studies: there are broad needs across many different sectors in terms of capacity building and opportunities for research in the future, including vulnerability mapping at different levels. The report concludes with a discussion of the feasibility of expanding the methods and tools used here to develop a tool box that could be used for cross-sectoral ex-ante assessment of interventions related to climate change and coping mechanisms. There are several challenges that have to be addressed, but there are good prospects for developing a useful framework.

The work has highlighted two other key points. First, even allowing for the technical problems and uncertainties associated with the analysis, it is clear that macro-level analyses, while useful, can hide enormous variability concerning what may be complex responses to climate change. There is considerable heterogeneity in households' access to resources, poverty levels, and ability to cope. Vulnerability and impact assessment work can certainly be usefully guided by macro-level analyses, but ultimately this work has to be done at regional and national levels. Second, these results have underlined that local responses to climate change through time are not necessarily linear. In terms of adaptation strategies, far more work is needed on the dynamics of change through time and on the dynamics of household responses. If adaptation itself has to be seen as an essentially dynamic, continuous and non-linear process, this has considerable implications for the tools and methods needed to guide it, and for the indicators and threshold analyses that will be needed.

The sciences of climate modelling and vulnerability assessment are developing rapidly, and over time some of the key technical issues that remain are likely to be resolved. At the same time, there are several other issues that have to be addressed. One is the necessity of communities starting to take centre stage in conducting vulnerability analysis and implementation to enhance their long-term capacities for adaptation. Another is the organisational changes that are needed to face the threat that climate change poses to development: climate change is inevitable, and it will add burdens to those who are already poor and vulnerable. A third issue is that Africa appears to have some of the greatest burdens of climate change impacts, certainly from the human health and agricultural perspectives; it is a region with generally limited ability to cope and adapt; and it has some of the lowest per capita emissions of the greenhouse gases that contribute to global warming. The likely impacts of climate change thus present a global ethical challenge as well as a development and scientific challenge, and this challenge has to be addressed by all of us.

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Background

1 Background

The world's climate is continuing to change at rates that are projected to be unprecedented in recent human history. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001) indicates that the global average surface temperature increased by about 0.6 °C during the twentieth century, and that "… most of the warming observed over the last 50 years is attributable to human activities." The IPCC climate model projections for the period between 2001 and 2100 suggest an increase in global average surface temperature of between 1.4 and 5.8 °C, the range depending largely on the scale of fossil-fuel burning within the period and on the different models used. More recent modelling work indicates that the temperature increases to 2100 may be larger than those estimated in 2001 (Stainforth et al., 2005; Lovelock, 2006).

The impacts of climate change are likely to be considerable in tropical regions. Overall, crop yields may fall by 10 to 20% by the year 2050 because of warming and drying, but there are places where yield losses may be much more severe (Jones and Thornton, 2003). Developing countries are generally considered more vulnerable to the effects of climate change than more developed countries, largely attributed to a low capacity to adapt in the developing world (Thomas and Twyman, 2005). And of the developing countries, many in Africa are seen as being the most vulnerable to climate variability and change (Slingo et al., 2005). High levels of vulnerability and low adaptive capacity in the developing world have been linked to factors such as a high reliance on natural resources, limited ability to adapt financially and institutionally, low per capita GDP and high poverty rates, and a lack of safety nets (Thomas and Twyman, 2005). The challenges for development are thus considerable, not least because the impacts are complex and highly uncertain. Despite this, there is considerable and increasing activity on the part of development agencies and governments to come to grips with the challenges, including the development of appropriate adaptation strategies.

DFID's Central Research Department (CRD) is developing a research programme on climate change and development in sub-Saharan Africa. The overall aims of the programme are to improve the ability of poor people to be more resilient to current climate variability as well as to the risks associated with longer-term climate change. The programme is being designed to address four broad goals:

- Research to reduce uncertainty, including analytical assessments of vulnerability and implications for poverty reduction;

- Strengthening capacity, including that of African scientists, governments, civil society organizations, international bodies and donors to assess, plan and implement adaptation strategies;
- Supporting adaptation by rural and urban people, particularly the most vulnerable, by supporting action research that contributes to better understanding, more inclusion, and adaptive learning and management;
- Adding value to existing adaptation initiatives, to enable African scientists to apply expertise and carry out research in support of adaptation projects.

The research programme will consider the knowledge implications of interacting and multiple stresses, such as HIV/AIDS and climate change, on the vulnerability of the poor, and it will concentrate on approaches that work where government structures are weak.

To enable CRD to make informed decisions on where to locate the research and where to put in place uptake pathways for research outputs, information is required that relates projected poverty data with climate vulnerability for sub-Saharan Africa (SSA). As the climate change research will address issues of household and community resilience and mechanisms of adaptation, present and future climatic variability are important factors.

ILRI was asked to attempt some vulnerability mapping for SSA over a few months, from September 2005 to March 2006, if possible at a sub-national level that could be used to guide research resource allocation decisions, in terms of the question, where should activities be concentrated. ILRI has had previous experience of broad-brush mapping to assist in the targetting of livestock-related research aimed at poverty alleviation. The vulnerability mapping work described here can be seen as one extension of the livestock poverty mapping work of 2002. That work was undertaken to produce sets of maps that located significant populations of poor livestock keepers, and to assess in very broad terms how poor livestock keeping populations were likely to change by 2050. The key findings of that study were that (a) in terms of numbers of poor people and of poor livestock keepers, as far as could be ascertained, the critical areas are South Asia and sub-Saharan Africa; and (b), the impacts of population growth and climate change in livestock systems are likely to be considerable, pointing up the need for adaptation and mitigation work in sub-Saharan Africa. The study also identified several research needs, including the necessity of identifying better the likely hotspots of change, more collaborative assembling of global data sets, the importance of high-resolution poverty mapping, and better understanding of poverty –resource degradation links.

The work was reported in Thornton et al. (2002; 2003) and Kruska et al. (2003). The information generated was subsequently used in an animal health priority setting study for Asia and Africa (Perry et al., 2003). The broader impacts of the livestock mapping work are not easy to ascertain, although the work did stimulate support to the production of high-resolution country poverty maps in East Africa (these now exist for Kenya and Uganda and is being finalized for Tanzania). It has also stimulated other studies that seek to identify the spatial determinants of poverty and the relationship between poverty and environmental degradation (see, for example, Kristjanson et al., 2005). It may also have had a modest influence on priority setting in other agencies and in targeting livestock investments.

The work described in this report is one small piece of a much larger activity that has involved DFID in commissioning several studies on the issue of climate change and appropriate research for development. These include the Africa Climate Report (Washington et al., 2004), and Climate Change and Development: Consultation on Key Researchable Issues (Huq and Reid, 2005), among others. The latter study has helped to clarify the critical researchable issues. The work described below is designed to help throw some light on the question, where geographically in sub-Saharan Africa might research resources be concentrated to address effectively the issues of the poor and vulnerable in the face of inevitable climate change.

Project Objectives

2 Project objectives and activities

The objectives of the work were as follows:

1. To identify areas of sub-Saharan Africa where current and projected impacts of climate variability and climate change are likely to be significant, poverty rates high, and vulnerability to change high, over the next 10, 25 and 50 years.

2. Assess the feasibility of developing a decision support toolbox for priority setting, monitoring and evaluation that can be used to assess cross-sectoral technology, policy and management interventions aimed at improving the adaptive capacity and coping strategies of highly vulnerable households.

Several activities were undertaken to meet the objectives of the work. First, a small project inception meeting was held in Nairobi in September 2005, involving several potential research collaborators. The major outputs of the meeting were the following:

- Identification of the key elements of a composite vulnerability indicator, given data availability constraints.
- Some consensus on the analytical aspects of the work and how this should be approached.
- Ideas on engaging users and utilising their feedback on project activities and outputs.

These various elements are discussed further below, in Section 3.

Following on from the September workshop, data were assembled for the mapping work. These data collation and analysis activities are described in Sections 4 and 5 of the report, and revolved around information on climate change trends, climate variability and possible changes in variability, poverty data, and indicators of vulnerability and adaptive capacity.

A parallel set of activities over the period November 2005 to February 2006 was undertaken with the aim of assessing the information needs of decision-makers related to climate variability and climate change. A small survey of actual and potential users was carried out, and a synthesis of findings is discussed in Section 6 below, together with a discussion of capacity building needs and opportunities for the future, and a discussion of the feasibility of expanding the methods and tools used here to develop a tool box that could be used for ex-ante assessment of interventions related to climate change and coping mechanisms.

Following the text of the main report, there is a series of Notes on different topics of relevance to different issues. These Notes are appropriately referred to in the text and provide details on several key aspects of vulnerability impact assessment concepts, methods and tools.

Framework for the study

3 Framework for the study

The literature on vulnerability and its assessment is very large, and continues to increase rapidly. There are still different notions on what vulnerability is, and how it is related to risk and adaptive capacity. Some of the various definitions of vulnerability are reviewed in Adger et al. (2004) and Vincent (2004). Brooks et al. (2005) point out that even in the IPCC TAR (2001), there is inconsistent use of the term. O'Brien et al. (2004) summarise two competing interpretations of vulnerability in the climate change literature: the first interpretation, or the "end point" approach, views vulnerability as a residual of climate change impacts minus adaptation. The second interpretation, or the "starting point" approach, sees vulnerability as a general characteristic generated by multiple factors and processes. Viewing vulnerability as an end point considers that adaptations and adaptive capacity determine vulnerability, whereas viewing vulnerability as a starting point holds that vulnerability determines adaptive capacity. O'Brien et al. (2005, page 5) consider that

> "… the end point approach originates from a perception that diagnoses climate change as the main problem; cures entail greenhouse gas emissions reductions and reduction of the sensitivity of various economic, social and environmental sectors and systems to projected changes in particular climate parameters. The starting point approach diagnoses inherent social and economic processes of marginalization and inequalities as the causes of climate vulnerability and seeks to identify ways of addressing these."

They argue that these approaches entail different diagnoses of a problem and different cures. In general, it seems that much current literature on vulnerability is taking more of a starting point approach. If vulnerability to climate change is seen as a state that is governed not just by climate change but by multiple processes and stressors, then there are multiple points for intervention that may go well beyond technological adaptations, to enhance people's ability to cope with present-day climate variability and long-term climate uncertainty (O'Brien et al., 2004).

The basis for the work outlined here (as in many other vulnerability studies) lies in identifying and treating two types of vulnerability: biophysical vulnerability, or the sensitivity of the natural environment to an exposure to a hazard; and social vulnerability, or the sensitivity of the human environment to the exposure. An impact is then seen as being a function of hazard exposure and both types of vulnerability. A framework to illustrate this is shown in Figure 1, taken from Vincent (2004) (which was adapted from Smith (2001)). This marries the notions of vulnerability, coping ability (or range), and adaptive capacity.

> "Exposure to a hazard such as climate change is a necessary prerequisite for an impact. Whether that exposure translates into a hazard depends on the nature of the vulnerability: if the natural environment is particularly sensitive and the human population is of low economic status with poor preparedness and few social institutions to facilitate coping then the impact will be high. If the social vulnerability is lower due to a more appropriate coping capacity, then exposure of the same nature may result in a lesser or even no impact." (Vincent, 2004, page 7).

As Vincent (2004) notes, many African societies are well-adapted to the climate variability to which they are exposed (Mortimore, 1998), and she considers that this variability is a good proxy for risks associated with future climate change, provided that the rate of change is sufficiently slow (Brooks and Adger, 2003). In the framework of Figure 1, adaptive capacity to climate change can be improved by expanding the coping range and thus reducing vulnerability.

Within the spirit of the "starting point " approach, Figure 2 shows one take on a systems (bottom-up) approach to vulnerability assessment that starts at the local or community level, from Huq and Reid (2004). Again, the key points seem to be the need to combine notions of biophysical and social vulnerability with understanding of the risks or hazards faced.

These sorts of ideas have been operationalised in many ways, some of which involve mapping. An example is the work of TERI (2003) on defining vulnerability profiles for Indian agriculture at the district level (Figure 3). In this study, adaptive capacity was examined in relation to the sensitivity of areas to both climate and international trade. Note 1 (page 112 below) discusses adaptive capacity and presents more details on the TERI case study.

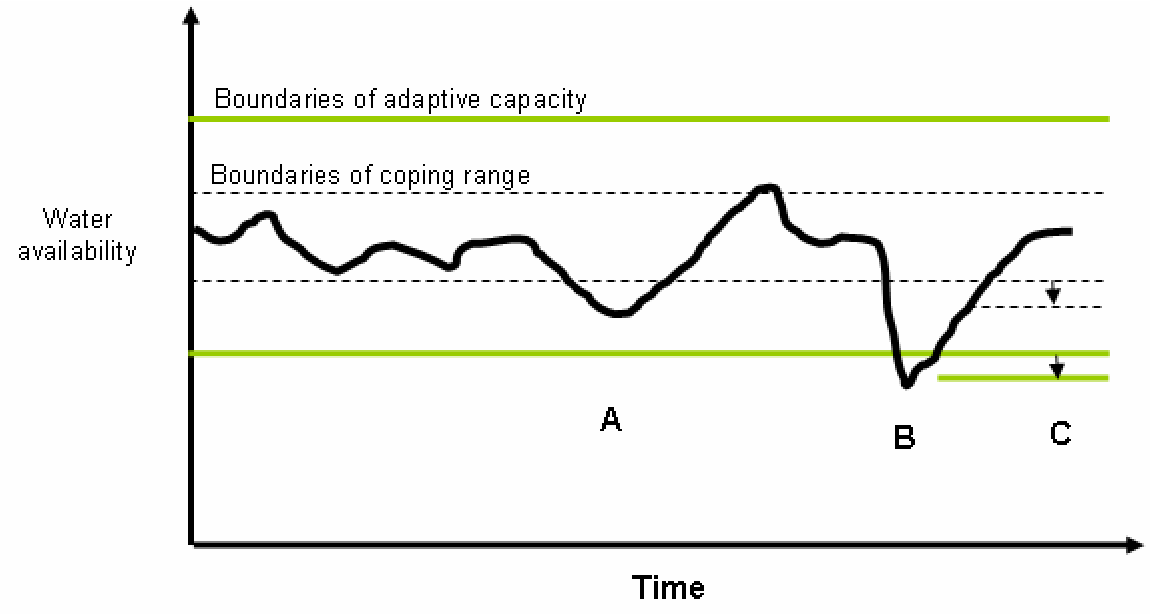

Figure 1. Representation of vulnerability, coping range and adaptive capacity, from Vincent (2004).

The time trace shows the variation in water availability for a region with a limited coping range.

At point A, the coping range is exceeded, but water availability is still within the adaptive capacity, and impact can be avoided provided that anticipatory and reactive adaptation mechanisms operate.

At point B, the adaptive capacity is exceeded. Ideally, the region will learn following hazard exposure and be able to expand its adaptive capacity for future situations (at point C).

If the long-term ability of the region to expand its adaptive capacity is exceeded, then impacts cannot be avoided.

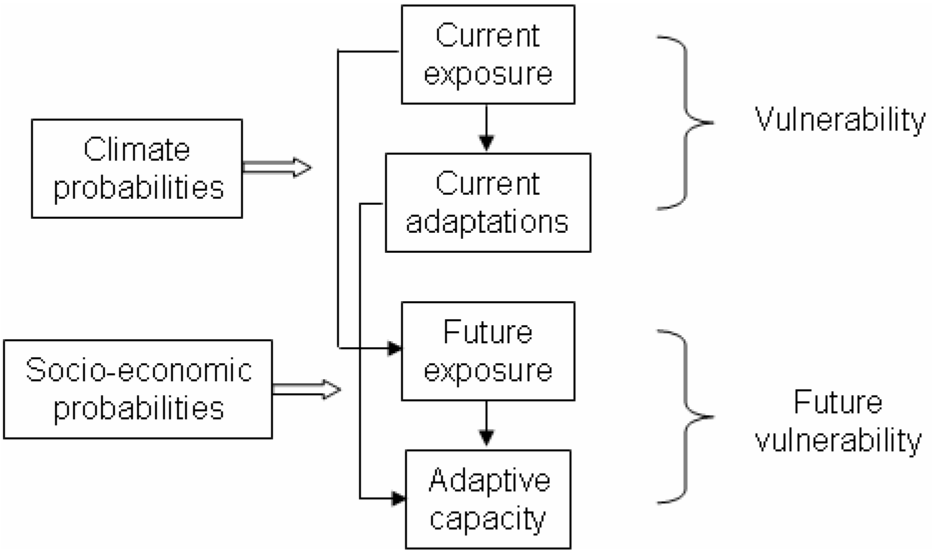

Figure 2. Systems approach – vulnerabilities, from Huq and Reid (2004), attributed to B Smit

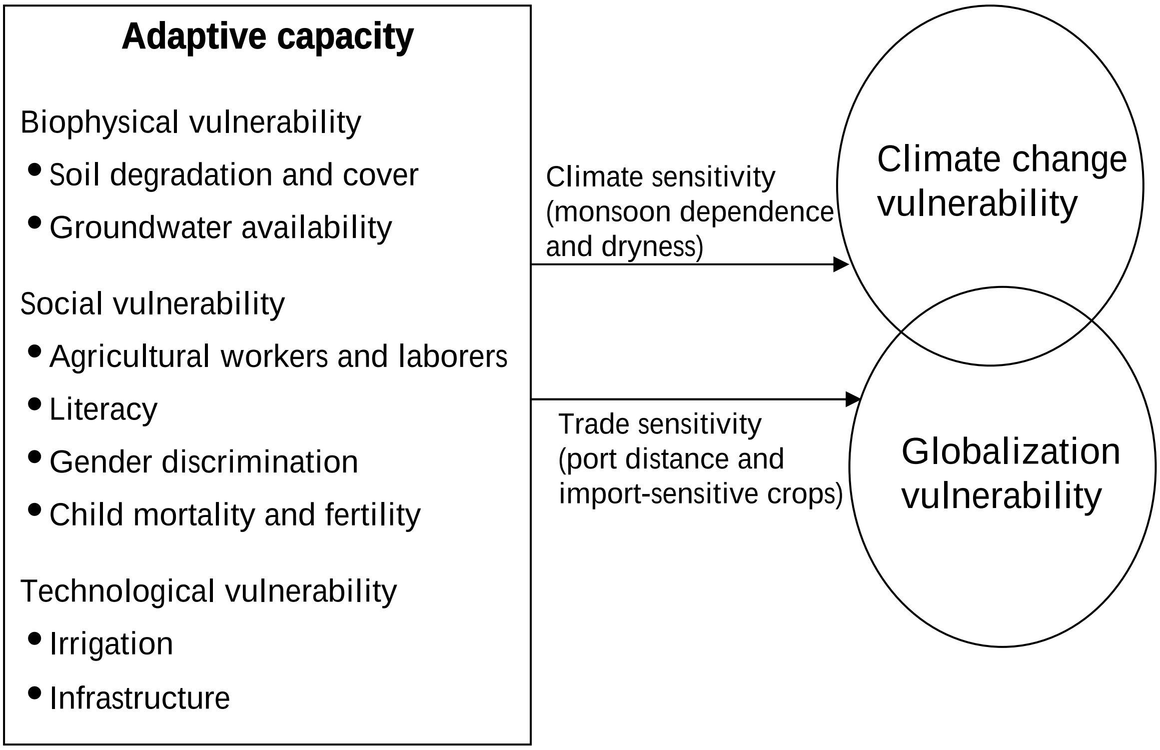

Figure 3. Elements of vulnerability profiles (TERI, 2003)

Conceptually, there is still a considerable amount of work to be done on frameworks for vulnerability assessment. From the experiences of the Millennium Ecosystem Assessment, Kasperson and Dow (2005) highlight several areas that need attention. These include relationships across scales and the role of specific actors, which they see as being still poorly represented in most frameworks. They also indicate that there is still a need for a clear nomenclature to make assessments consistent and coherent (Kasperson and Dow, 2005). Indeed, recent literature in the area of poverty traps and the existence and importance of multiple thresholds (see Barrett and Swallow (2006), for example) may hold promise for contributing to further development of assessment frameworks.

For the current study, we have taken a highly pragmatic approach. At the project inception workshop in September 2005, considerable attention was given to the basic ideas associated with mapping vulnerability and to the issue of data availability and the utilization of continental-scale data sets and different proxies that could be used to combine the ideas of risk and biophysical and social vulnerability. We have thus taken a “starting-point” approach to vulnerability within a systems context, and tried to combine it with a sustainable livelihoods approach. There were two major stages in the analysis.

The first stage was to identify those areas of sub-Saharan Africa that appear to be particularly at risk from climate change in the coming 50 years. This focused on identifying geographic areas where changes in temperatures and rainfall amounts and patterns etc. may be relatively large. This was done by downscaling the outputs from several Global Circulation Models and various scenarios of the future. Changes in the length of growing season between now and 2020 and 2050 were estimated, overlaid with information on current weather variability and very coarse indicators of how this variability might change. The results were combined with two existing agricultural systems classifications, on the basis that land-use options define at least part of the livelihood strategies for millions of rural people who depend on natural resources to some extent for their well-being. The outputs from this stage of the work are data tables and maps showing a breakdown of projected country-by-system climate changes under differing scenarios of the future, classified into broad groups. We also did an analysis of possible changes in the number of growing seasons and in the probabilities of season failure. This work is outlined and summarised in Section 4 below.

The second stage was to characterize sub-Saharan Africa (on the same country-by-system basis) in terms of a set of vulnerability indicators. One of the outputs of the workshop in September

2005 was a list of possible proxies that could be used as vulnerability indicators, and these were grouped into the five asset types associated with the sustainable livelihoods approach: human, financial, physical, social and natural following Carney (1998). Subsequently, the list was revised somewhat in the light of data availability, but the original list was left as intact as possible. Indicators of biophysical and social vulnerability were adopted or formed from existing data, some at national level and others at sub-national level, and these were assembled into one “overall” vulnerability indicator using Principal Components Analysis (PCA). The country-by-system climate change classes from stage one were then qualitatively combined with the most vulnerable two quartiles of this overall indicator, and the results synthesised for two different scenarios of the future. This work is reported in Section 5, along with indicative results of the analysis.

The possible uses of this kind of information are discussed in Section 6, in the light of a small survey of potential users undertaken in this project, and related also to much broader scoping studies carried out under the auspices of DFID and other organizations on climate change research and capacity building needs in Africa. Section 6 also contains a discussion on the limitations of the current work, and some suggestions on how to improve both the information produced and its relevance to wider groups of stakeholders.

Climate Impacts

4. Climate impacts in sub-Saharan Africa

In a comprehensive paper on climate change in Africa over the period 1900 to 2100, Hulme et al. (2001) showed that climate change is not simply a phenomenon of the future, but one of the relatively recent past. The continent is warmer than it was 100 years ago. Warming occurred through the twentieth century at the rate of about 0.5 °C per century. Hulme et al. (2001) also illustrate the large regional differences that exist in rainfall variability. The Sahel, for example, has displayed considerable multi-decadal variability with recent drying. East Africa appears to have a relatively stable rainfall regime, although there is some evidence of long-term wetting. South-east Africa has a relatively stable regime too, but with marked inter-decadal variability.

The future of climate change in Africa presents different problems, of course. There is a distribution of future climate changes, due to both incomplete understanding of the climate system and the inherent unpredictability of climate. While this distribution is unknown, sensible guesses can be made on its magnitude and shape, and choices can always then be made so as to sample a reasonable part of its range (Hulme et al., 2001).

What we have done here is to downscale outputs from GCM models, i.e., use methods to interpolate model output from the relatively coarse grid sizes that GCMs currently utilize (typically cells of side 2 to 3 ° latitude and longitude) to higher spatial resolutions. There are various methods that can be used to downscale the outputs from GCMs (Jones et al., 2005), although considerable care may be necessary in interpreting the results of such downscaling (Mitchell, 2003). Once GCM output had been downscaled, we then looked at possible changes in rainfall patterns and amounts and temperatures, compared possible future scenarios with current conditions, and used these comparisons as a basis for identifying areas that are more likely to be affected by climate change than others. Because we wanted to relate possible climate change impacts to livelihoods, we used the length of the growing period as an indicator of agricultural sensitivity to climate, thereby integrating changes in both rainfall and temperature.

For changes in weather variability, we developed a surface of the coefficient of variation of annual rainfall for Africa using downscaled GCM outputs and a weather generator. Developing surfaces of rainfall CV for future possible climates in any meaningful way is still difficult, so current rainfall CV and changes in rainfall amounts were used as proxies for future conditions. We also carried out continent-wide analyses of the possible changes in probability of season failure, for the cropping areas of sub-Saharan Africa. For that analysis, we omitted both very dry and very wet areas. These various analyses are described below.

4.1 Data and analysis

Different scenarios of climate change to 2050 were considered using the data set TYN SC 2.0 kindly supplied by its originator, Timothy D Mitchell (Mitchell et al., 2004). The variables used from this data set were the diurnal temperature range, precipitation and average daily temperature on a monthly basis. The data cover the global land surface at a resolution of 0.5 degrees latitude and longitude, and cover the period 2001 to 2100. There are 20 climate change scenarios in the complete data set. The climate change scenarios are made up of all permutations of five Atmosphere-Ocean General Circulation Models (AOGCMs) (HadCM3, CSIRO2, CGCM2, PCM, ECHam4) and four SRES scenarios (A1FI, A2, B1, B2). The five models used in this data-set (see Table 1) were among the set of state-of-the-art coupled climate models used by the IPCC (2001) in the Third Assessment Working Group 1 Report. A summary of their features may be found in IPCC (2001). The month-to-month and year-to-year variations are superimposed on top of the averaged climate changes taken from the models; these are taken from the gridded observations in a companion data-set, CRU TS 2.0 (New et al., 2002). The two data sets together thus provide complete time-series for the period 1901-2100.

Details of the SRES scenarios can be found in IPCC (2000), and these are summarized in Table 2. The “A” scenarios have more of an emphasis on economic growth, the “B” scenarios on environmental protection. The “1” scenarios assume more globalisation, the “2” scenarios more regionalization. The SRES scenarios have come in for some criticism, partly to do with the fact that the projections for human population have become out-of-date surprisingly rapidly. While some have criticized the population and economic details, the scenarios are generally internally consistent and constitute a very useful set of standards, and the range of future greenhouse gas emissions is undisputed (Tol et al., 2005).

Table 1. AOGCMs in the TYN SC 2.0 data set (from Mitchell, 2003)

Short Name	GCM Name	Reference	Resolution	Code
CGCM 2	Canadian Global Climate Model version 2	Flato and Boer (2001)	3.8 x 3.8 degrees	CG
CSIRO 2	Commonwealth Scientific and Industrial Research Organisation GCM mark 2	Gordon and O'Farrell (1997)	3.2 x 5.6 degrees	CS
DOE PCM	National Centre for Atmospheric Research Parallel Climate Model	Washington et al. (2000)	2.8 by 2.8 degrees	PC
HadCM3	Hadley Centre Coupled Model version 3	Mitchell et al. (1998)	2.5 x 3.75 degrees	HD
ECHam4	European Centre Hamburg GCM version 4 (Max Planck Institute for Meteorology)	Roeckner et al (1996)	2.8 x 2.8 degrees	EC

The data set allows us to represent the uncertainty in climate impacts arising from two distinct sources of uncertainty: uncertainty in the future emissions of greenhouse gases, and uncertainty in climate modelling. Between them, the 20 scenarios cover 93% of the possible range of future global warming estimated by the IPCC in their Third Assessment Report (2001).

Length of growing period changes

For the analysis, we started with the 1-km interpolated climate grid for the globe named WorldCLIM (Hijmans et al., 2005), which was considered to be representative of current climatic conditions (most of the data cover the period 1960-1990). This uses data from a number of databases, including the climate database at the International Centre for Tropical Agriculture (CIAT). WorldCLIM uses thin plate smoothing with a fixed lapse rate employing the program ANUSPLIN. The algorithm is described in Hutchinson (1989). To save time, Africa was cut out of the global coverage, and the climate grid reassembled to a resolution of 10 arc-minutes to make the analysis programmes run faster. This grid file of climate normals was considered to be representative of current conditions for the continent. Each pixel in the file has latitude, longitude, elevation, and monthly values for average daily temperature (°C), average daily diurnal temperature variation (°C), and average monthly rainfall (mm).

Table 2. The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES) (IPCC, 2000)

A1. The A1 storyline and scenario family describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

B1. The B1 storyline and scenario family describe a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

A similar climate grid files was then prepared for each combination of the five GCMs and four SRES scenarios, for the years 2015, 2030, 2045 and 2060. This involved fitting quadratic regressions to every pixel at the resolution of the TYN SC 2.0 data set (0.5 x 0.5° latitude and longitude) for the period 1985 to 2060 at 15-year intervals (i.e. six points). The regression fit was excellent in all areas apart from some polar regions, and the root mean square error (RMSE) was negligible. To generalize the process, files of the three regression coefficients and the RMSE associated with each pixel were formed (note that these are difference data associated with a particular combination of GCM and SRES scenario).

To interpolate back to the 10-minute grids, the differences between the monthly rainfalls, temperatures and diurnal temperature ranges were calculated from the regression equations for each pixel in the coarse GCM grid. For each pixel in the 10-minute grid, the interpolated value was obtained by inverse square distance weighting following Jones and Gladkov (1999) and Jones and Thornton (2000).

The length of growing period was calculated as follows. For each 10-minute pixel in Africa, the climate normals data were read from the appropriate gridded file and interpolated to daily data using the method of Jones (1986). Potential evapo-transpiration was calculated according to Linacre (1977). The water balance was calculated using WATBAL (see Jones (1986) for the source) which uses the method of Keig and McAlpine (1974). It calculates the available soil water, runoff, water deficiency and the actual to potential evapotranspiration ratio (Ea/Et). The source code is a simplified version of Reddy (1979). Ea/Et is calculated from a square root function that fits the three points supplied by Reddy depending on soil water holding capacity. A moderate soil water holding capacity of 100 mm was assumed for all soils. On running the water balance simulation, the number of days with Ea/Et greater than 0.5 were counted as potential growing days from day-of-year 1 to day-of-year 365. A further restriction was placed to eliminate cold highland areas. Days with average temperature less than 9 °C were not counted as growing days even if water was not limiting.

Results were output as IDRISI images for easy display and manipulation (Eastman, 2001), which involved the production of difference maps for length of growing period (LGP), rainfall and temperatures for conditions in 2020 and 2050 for each combination of GCM and SRES scenario, compared with current conditions. No efforts were, however, made to distinguish unimodal and bimodal rainfall patterns in terms of LGP. This will need to be taken into account for more detailed studies of specific areas. In addition, more refined analysis will involve estimation of water holding capacities from the FAO soils map; it would be interesting (although time consuming) to look at the differences due to the soil factor.

Rainfall variability

Using the 10-minute climate normals grid for current conditions outlined above, the weather generator MarkSim (Jones and Thornton, 2000) was used to simulate 1000 years of daily weather data for every pixel in Africa. The mean and standard deviation of annual rainfall for the pixel and the coefficient of variation of rainfall were then calculated. Previously, estimates of CV generated using MarkSim have been found to be highly unstable, and so 1000 replicates of annual rainfall are needed. A complete simulation of Africa takes several days of continuous computer time at 10-minute resolution. There were some eight pixels for which MarkSim was not able to generate data. For these pixels, mean rainfalls were calculated from the climate normals grid, and standard deviations were estimated as the arithmetic mean of the standard deviations of the eight near neighbours of each pixel.

In addition to changes in LGP to 2050, it would be very useful to be able to estimate changes in rainfall variability to the same date. This cannot be done using the methods outlined here; characteristic daily data from the climate normal grids for possible future conditions can be generated using MarkSim, but that will assume that the underlying variability of rainfall for each climate type will be the same then as it will be now. This may well not be case, and while there is some information on the direction of trends in rainfall variability to the end of this century, there is considerable uncertainty and differences exist between the various GCMs (Hulme et al., 2001). This aspect requires more attention in the future with the further development and application of Regional Climate Models for areas of Africa.

IPCC (2001) noted that increases in mean precipitation are likely to be associated with increases in variability, and precipitation variability is likely to decrease in areas of reduced mean precipitation. Many studies have shown tendencies for inter-annual rainfall variation to increase. In many regions, including parts of Africa, interannual climatic variability is strongly related to ENSO, and thus will be affected by changes in ENSO behaviour (Hanson et al., 2006).

Mapping changes to the probability of season failure

An analysis of season length for Africa was also undertaken using the weather generator MarkSim (Jones and Thornton, 2000) to downscale several scenarios from the HadCM3 and ECHam4 GCMs. Because of the considerable computational requirements of this work, the analysis here concentrated on only certain environments where we felt growing season length and reliability would be of prime concern. (This type of analysis can be repeated for broader environments at a later stage). The wet climates, where the Köppen criterion of at least 60 mm rainfall was fulfilled for eight or more months of the year, were omitted from the analysis. Although there can be water stress in these environments, it was not considered that it would be sufficient to curtail the growing season. Dry climates with two or less Köppen wet months were eliminated as unsuitable for cropping, although extensive grazing might still be practised in these areas. A minimum growing season temperature of 9 °C was applied. This was deliberately set at a low level to allow for inclusion of new areas owing to temperature increase.

MarkSim was used to simulate 30 years of independent seasons and WATBAL was used to calculate the water balance for each pixel for each year. Growing season days were determined using the following rules. Season start was deemed to occur when five consecutive days experienced a ratio of actual to potential evapo-transiration (Ea/Et) greater than 0.8. This is sufficient to allow for reasonable germination in most crops. Season end was determined when eight consecutive days had an Ea/Et ratio of less than 0.5. While this might not actually kill drought tolerant crops, it is a sufficient indicator that a major stress has occurred and often indicated the termination of a growing period.

The growing season sequences were tallied for each pixel for each year of simulation. In many cases, up to four growing periods (as defined above) were found, but in most cases the shorter ones were far too short to allow even the shortest season crop. A valid growing season was thus defined in a very conservative way as 50 growing days with Ea/Et greater than 0.5 and less than 20 stress days within this period with Ea/Et value of less than 0.5.

For this analysis, we decided to use the 1-km WorldCLIM climate grids. Because of the large numbers of pixels in the triage set (over 16 million), we used random sampling of the triage set and carried out interpolation from the calculated points to give us a reasonable precision. An index of the 16 million pixels was constructed and randomised with a key to refer to the relevant climate grid record in the triage set (running through the randomised index provides a consistent set of random points that are the same for all models and scenarios, if desired). After investigating the relationship between the density of random sampling and the precision obtained, we decided on a 5% sample of pixels, giving a mean distance of interpolation of less than three pixels (2.7 km). Results are described in the next section.

4.2 Identification of hotspots of change

There are considerable differences between SRES scenario and between the different GCMs, in terms of projected changes in temperatures, rainfall and length of growing periods in regions of Africa. Initial inspection of change maps to 2020 and to 2050 for all 20 combinations of GCM and scenarios suggested that differences in the detail of these analyses could be difficult to interpret. Accordingly, we decided to concentrate attention on a subset of the GCMs and scenarios.

In terms of selecting among the five GCMs, the justification for saying that one or two are "better" than the others depends on the purpose for which they are being used. Ideally, each of the GCMs could be tested by taking modelled output for the period 1961-1990, calculating length of growing periods (as an integrator of changing temperatures and rainfall) for each combination of GCM and scenario, and then comparing these with LGP derived from the observed 1961-1990 gridded data. One could then concentrate on the GCM(s) that better matched the observed LGP for current conditions with modelled LGP for current conditions. This is because GCM scenario runs are generally initialized using conditions from the early twentieth century. This kind of "backwards" testing would, however, require considerable time.

Considerable work has been done on testing large numbers of GCMs for their ability to represent observed climate conditions at a global or regional level. A recent comprehensive assessment is that of AchutaRao et al. (2004). Multi-model trends in rainfall for East Africa by McHugh (2005) suggests that certain GCMs are better able to simulate observed rainfall patterns in this region than others. The assumption is that if a GCM can better represent current conditions, then this will improve confidence in its ability to project future conditions under different scenarios of change, all other things being equal. McHugh (2005) identified five GCMs out of 19 that represent rainfall patterns in East Africa relatively well and two (HadCM3 and ECHam4) of which are in the data set used in this study. The preliminary results of work by

Hanson et al. (2006) also tend to support the use of these two GCMs for East African conditions. Liu et al. (2003) reported that for Sahelian conditions (rainfall of some 20 mm per year), these two GCMs were not the best performers in terms of reproducing current rainfall patterns, but they were better than several others.

An advantage of using these two GCMs is that ECHam4 is what might be termed a “wet” model – the rainfall differences projected under the four SRES scenarios from 2000 to 2050 are the largest of all the five GCMs used here. On the other hand, the HadCM3 is a “drier” model; rainfall differences for the four scenarios between 2000 and 2050 are the lowest or among the lowest for all the GCMs used here. Accordingly, we use these two GCMs for the analyses presented below. In general, there seems to have been relatively little validation work carried out on GCMs for African conditions (Hulme et al., 2001; D Conway, personal communication), and this is an area that would benefit from further work.

The number of SRES scenarios that were considered in the analysis was also reduced. As noted above, these scenarios cover a wide range of economic development, fossil fuel and population growth possibilities. Figure 4, slightly modified from Figure 9.14 in IPCC (2001), shows the envelope of global temperature increases associated with several GCMs and the various SRES scenarios. Most of the temperature range is covered by two scenarios, A1F1 and B1, and these were included in the TYN SC 2.0 data set used in this analysis. Accordingly, the vulnerability analysis results concentrate on the four combinations of two GCMS (HadCM3 and ECHam4) and two scenarios (A1F1 and B1).

First, we show some results that characterize current conditions for Africa. Figure 5 shows the length of growing period (days per year) for current conditions (the year 2000), at a resolution of 10 arc-minutes. The coefficient of variation of annual rainfall (the standard deviation of annual rainfall divided by the mean, expressed as a percentage) is shown in

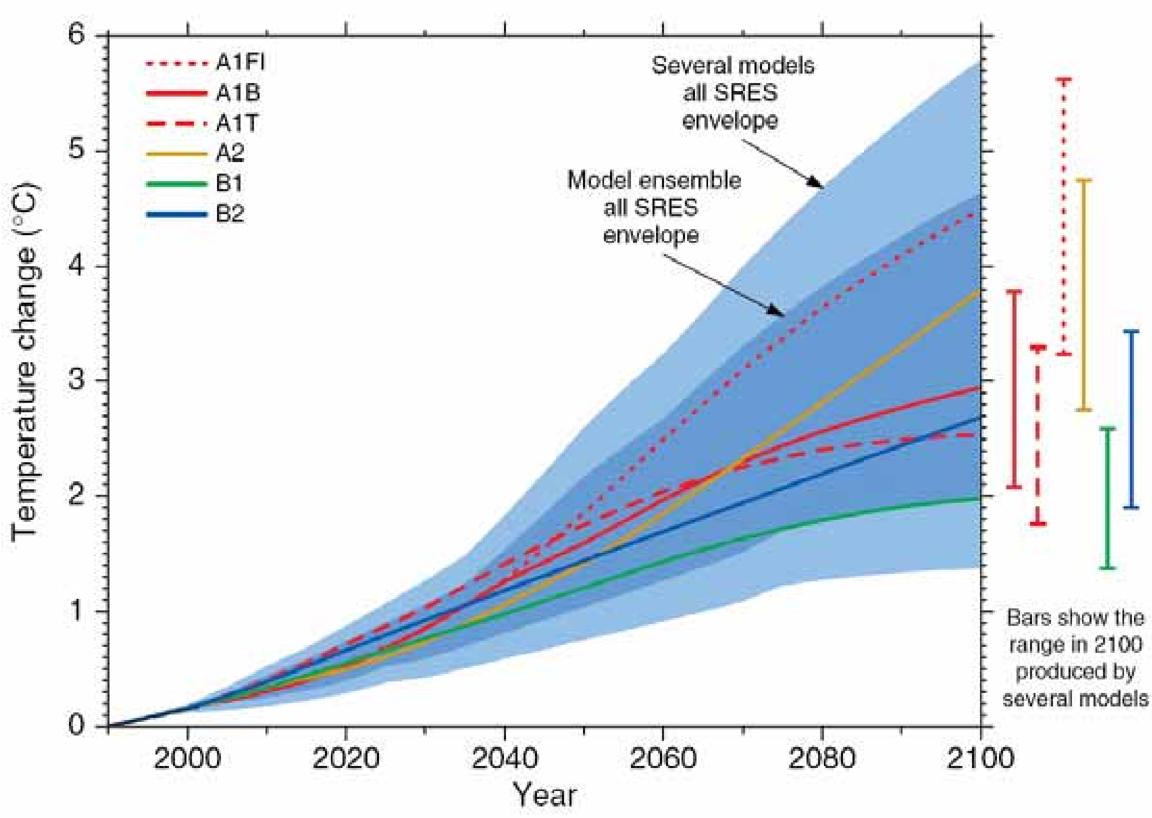

Figure 4. Estimated radiative forcing for the four illustrative SRES marker scenarios, illustrating different energy technology options; results relative to 1990. Slightly modified from Figure 9.14 in IPCC (2001).

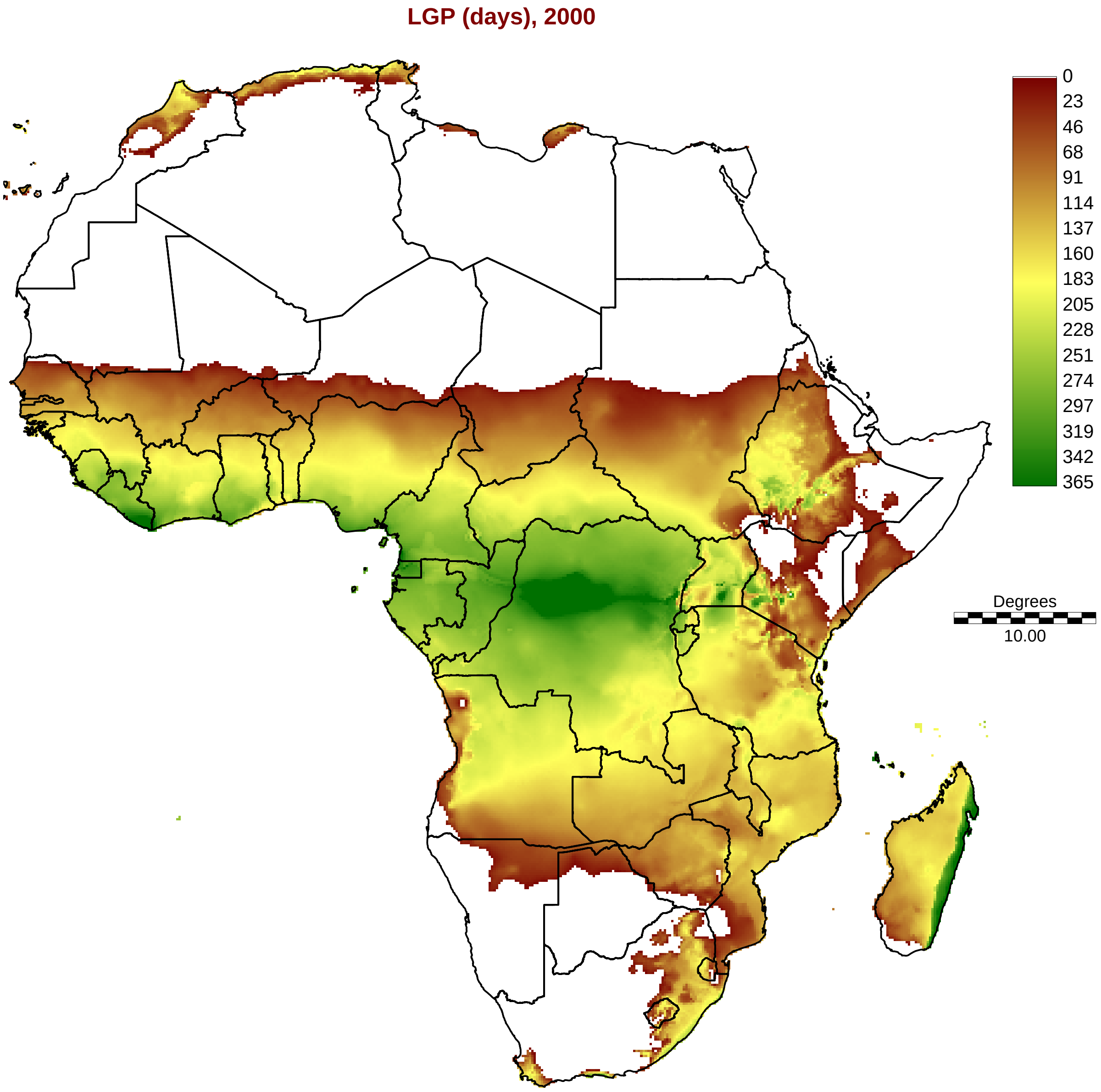

Figure 5. Length of growing period (days per year) for current conditions (2000).

Figure 6 for 2000, also at a resolution of 10 arc-minutes. These layers were derived as outlined above in section 4.1. A breakdown of values of the estimated CV for countries and systems of Africa is shown in Appendix 3.

Figure 7 shows maps of projected changes in LGP from 2000 to 2050, from downscaled outputs of the ECHam4 GCM for scenarios A1F1 and A2 (Figure 7(a)), and scenarios B1 and B2 (Figure 7(b)) and of the HadCM3 GCM for scenarios A1F1 and A2 (Figure 7(c)) and scenarios B1 and B2 (Figure 7(d)). Following IPCC (2001) map legends, these changes were classified into five classes: losses in LGP of > 20% ("large" losses); of 5-20% ("moderate" losses); no change (± 5% change); gains of 5-20% ("moderate" gains); and gains of >20% ("large" gains). Various points can be made about these maps. First, it should be noted that some of the large losses and large gains are located in areas with a LGP less than 60 days, i.e. in highly marginal areas for cropping. Second, there is considerable variability in results arising from the different scenarios, and there is also variability in results arising from the different GCMs used. Third, if anything could be generalized about these different maps, it is that under the range of these SRES scenarios and the GCMs used, many parts of sub-Saharan Africa are likely to experience a decrease in the length of growing period, and in some areas, the decreases may be severe. In other words, projected increases in temperature and projected changes in rainfall patterns and amount (increases in rainfall amounts are projected in many areas) combine to suggest that growing periods will decrease in many places. There are also a few areas where the combination of increased temperatures and rainfall changes may lead to an extension of the growing season, and these appear to occur in some of the highland areas.

Figure 8 presents maps that show changes in the length of growing period from 2000 to 2020, rather than to 2050, for the ECHam4 model and scenarios A1F1 and B1 (Figure 8(a)) and for the HadCM3 model and scenarios A1F1 and B1 (Figure 8(b)). As might be expected, projected changes are relatively muted compared with the changes to 2050, although there are still some large changes in LGP projected for marginal areas even within 20 years. There are also intriguing indications that there may be some areas under some scenarios that initially have an extension in LGP to 2020, but which by 2050 have lost growing days. This could be explained in terms of the early years of wetter and warmer conditions combining to enhance the growing season, but continued inexorable increases in temperature eventually more than off-setting the

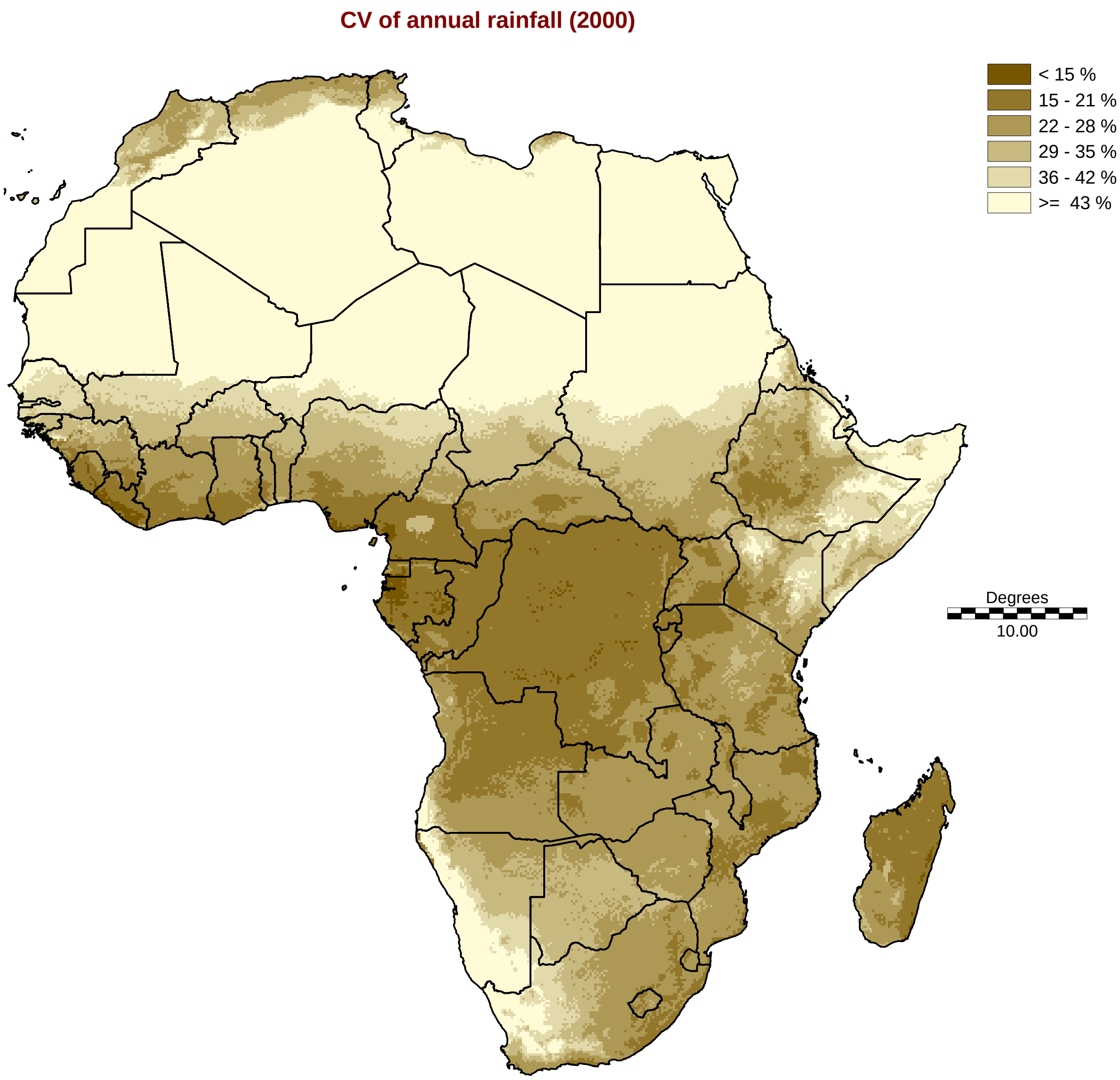

Figure 6. Coefficient of variation of annual rainfall (%) for current conditions (2000)

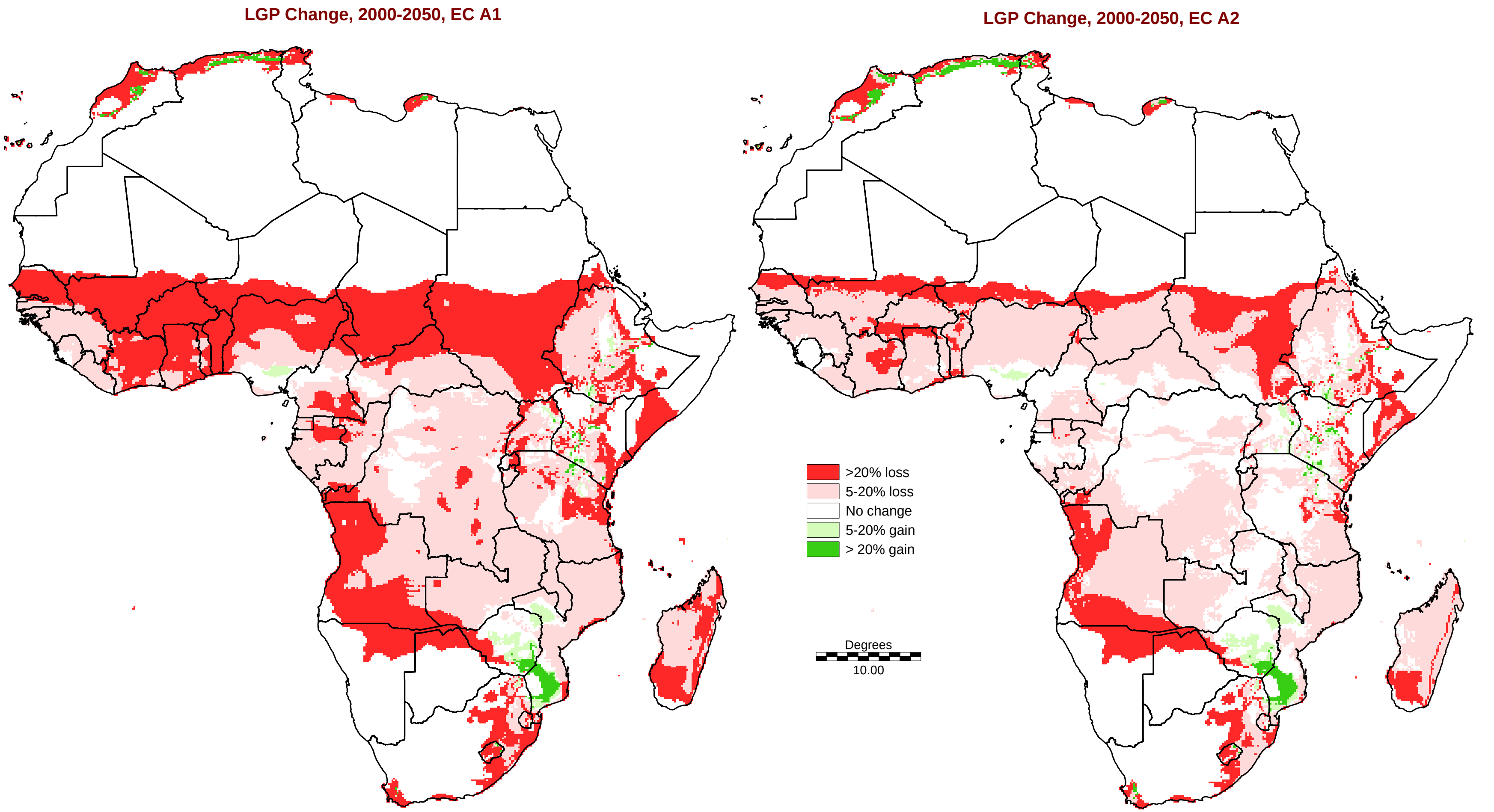

Figure 7 (A). Percentage changes in length of growing period to 2050, ECHam4 and scenarios A1F1 and A2

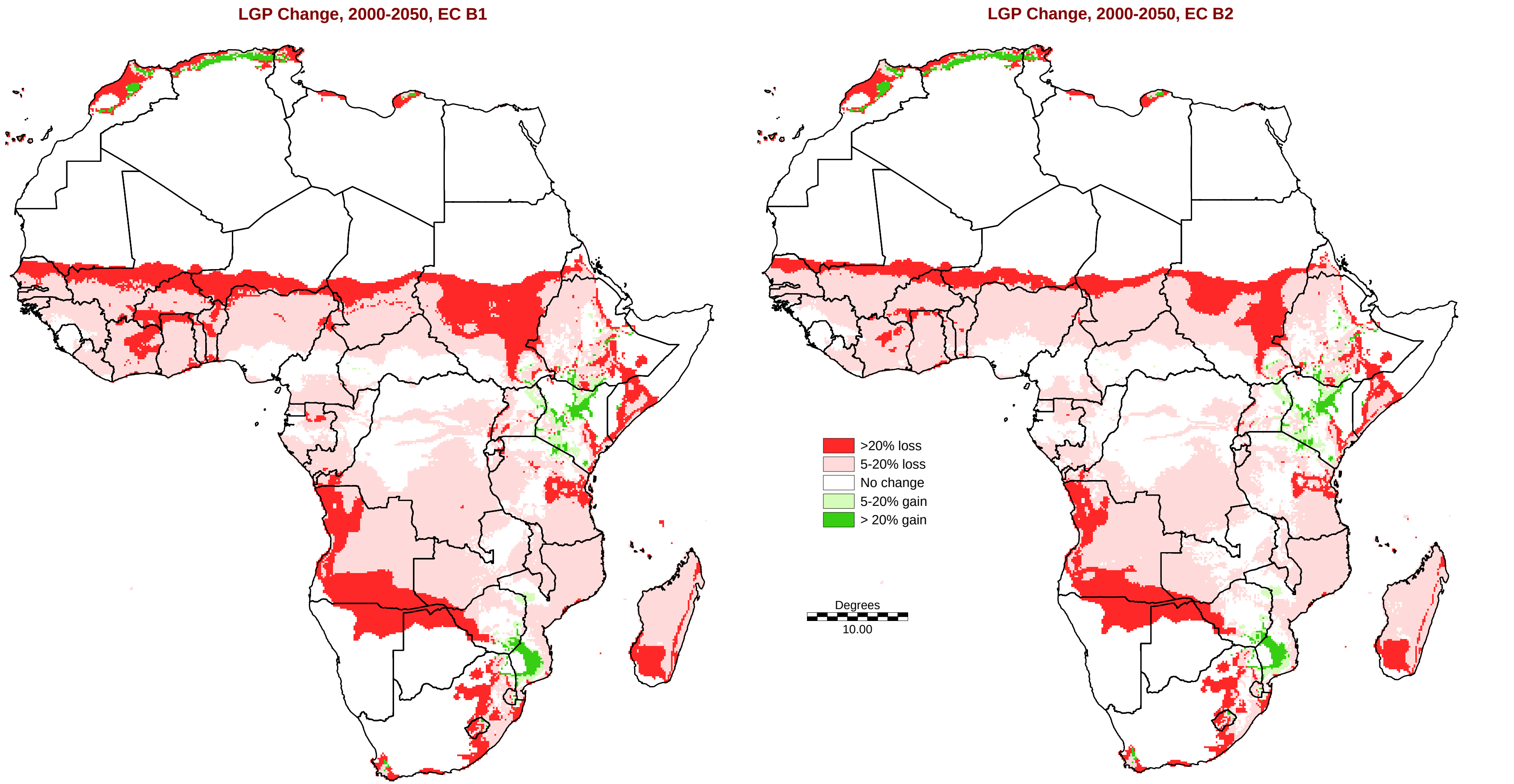

Figure 7 (B). Percentage changes in length of growing period to 2050, ECHam4 and scenarios B1 and B2

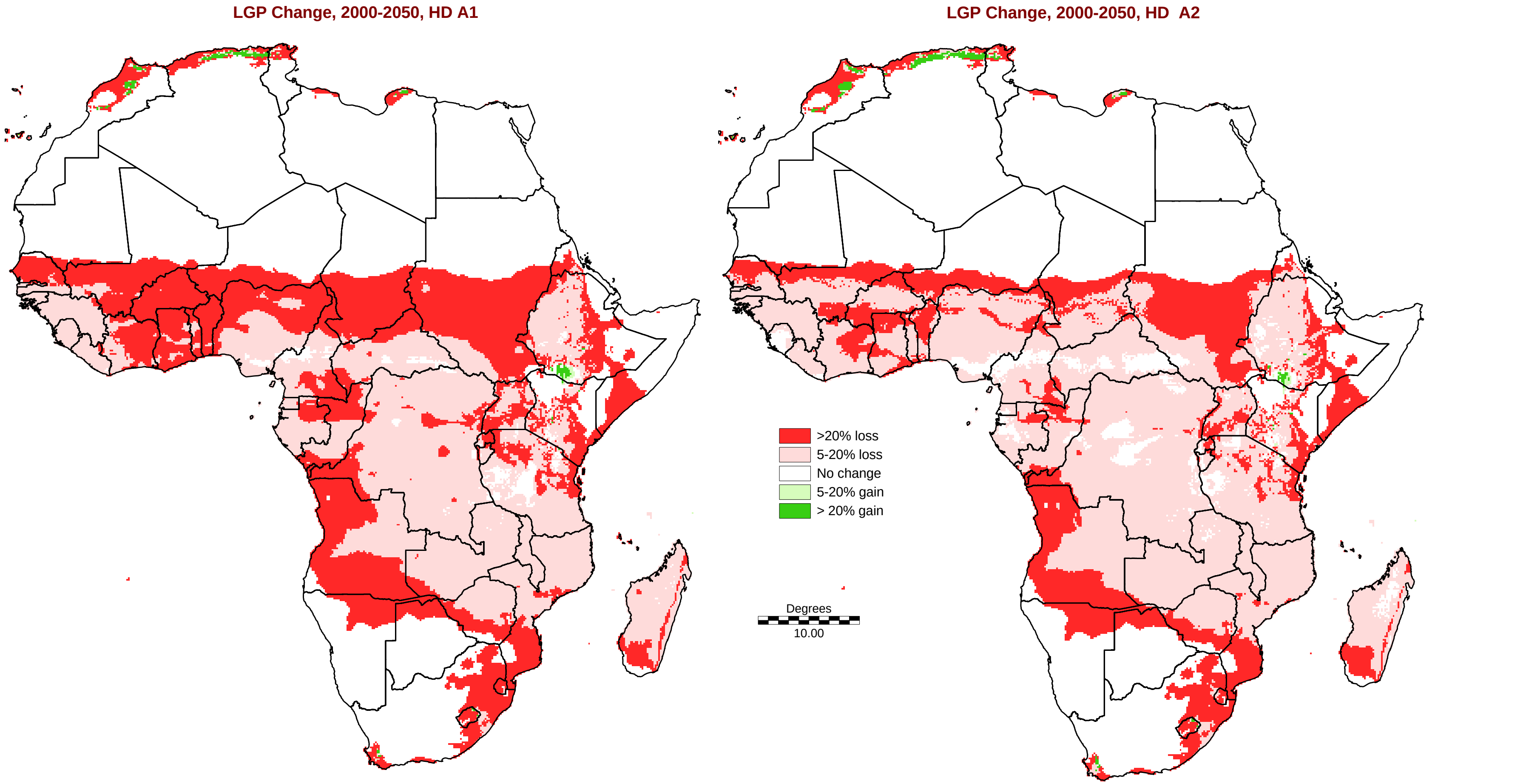

Figure 7 (C). Percentage changes in length of growing period to 2050, HadCM3 and scenarios A1F1 and A2

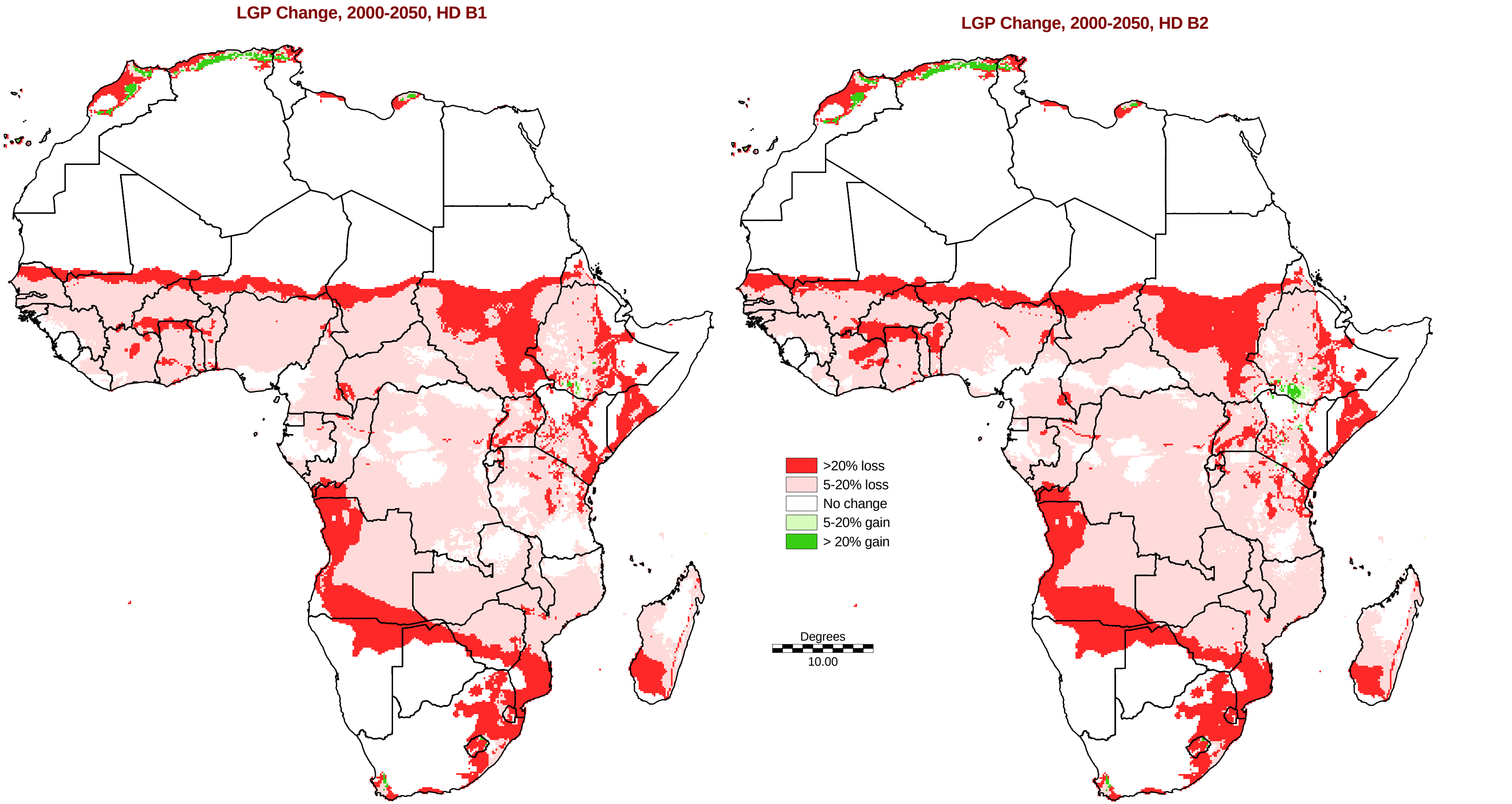

Figure 7 (D). Percentage changes in length of growing period to 2050, HadCM3 and scenarios B1 and B2

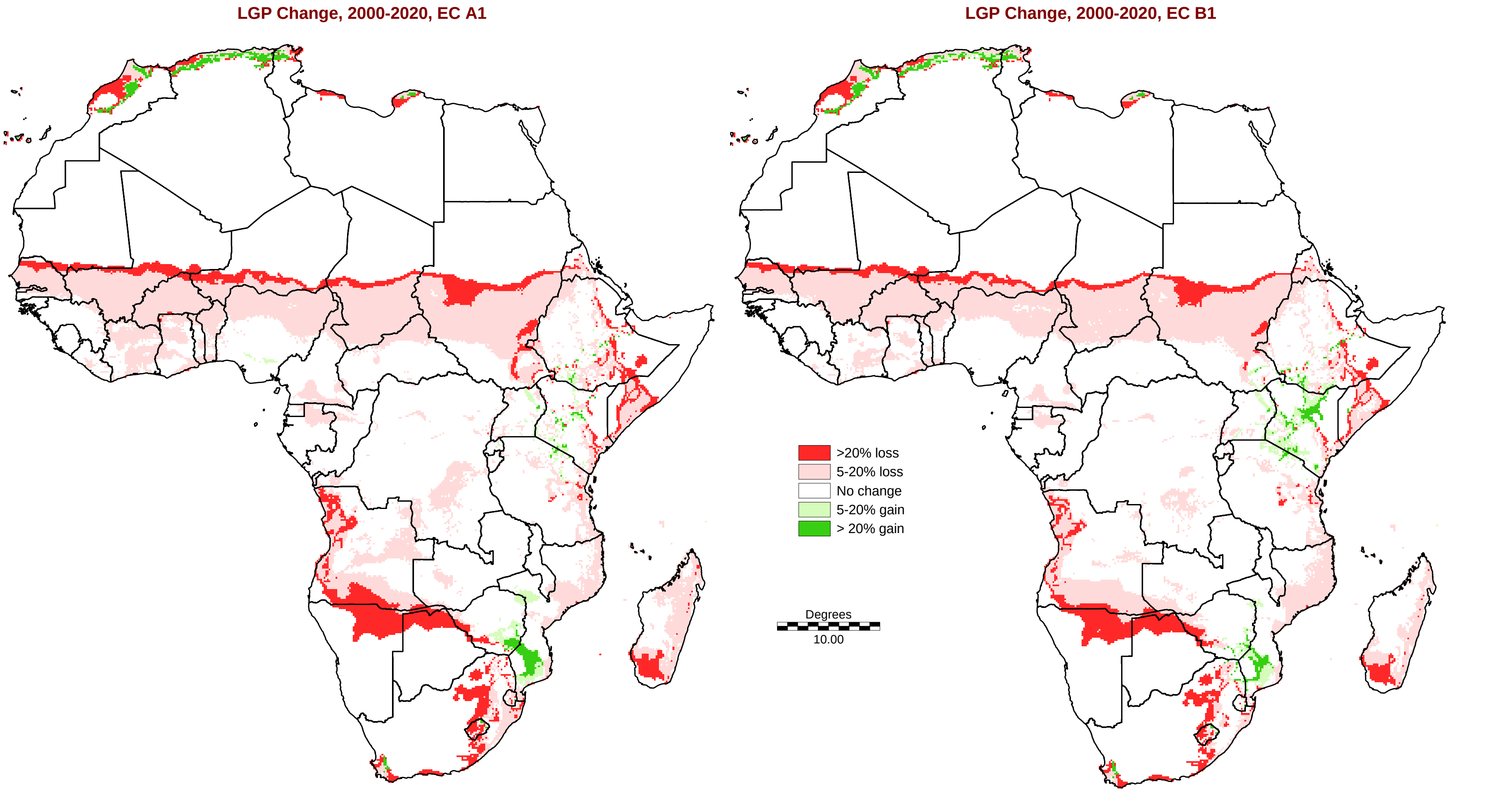

Figure 8 (A). Percentage changes in length of growing period to 2020, ECHam4 and scenarios A1F1 and B1

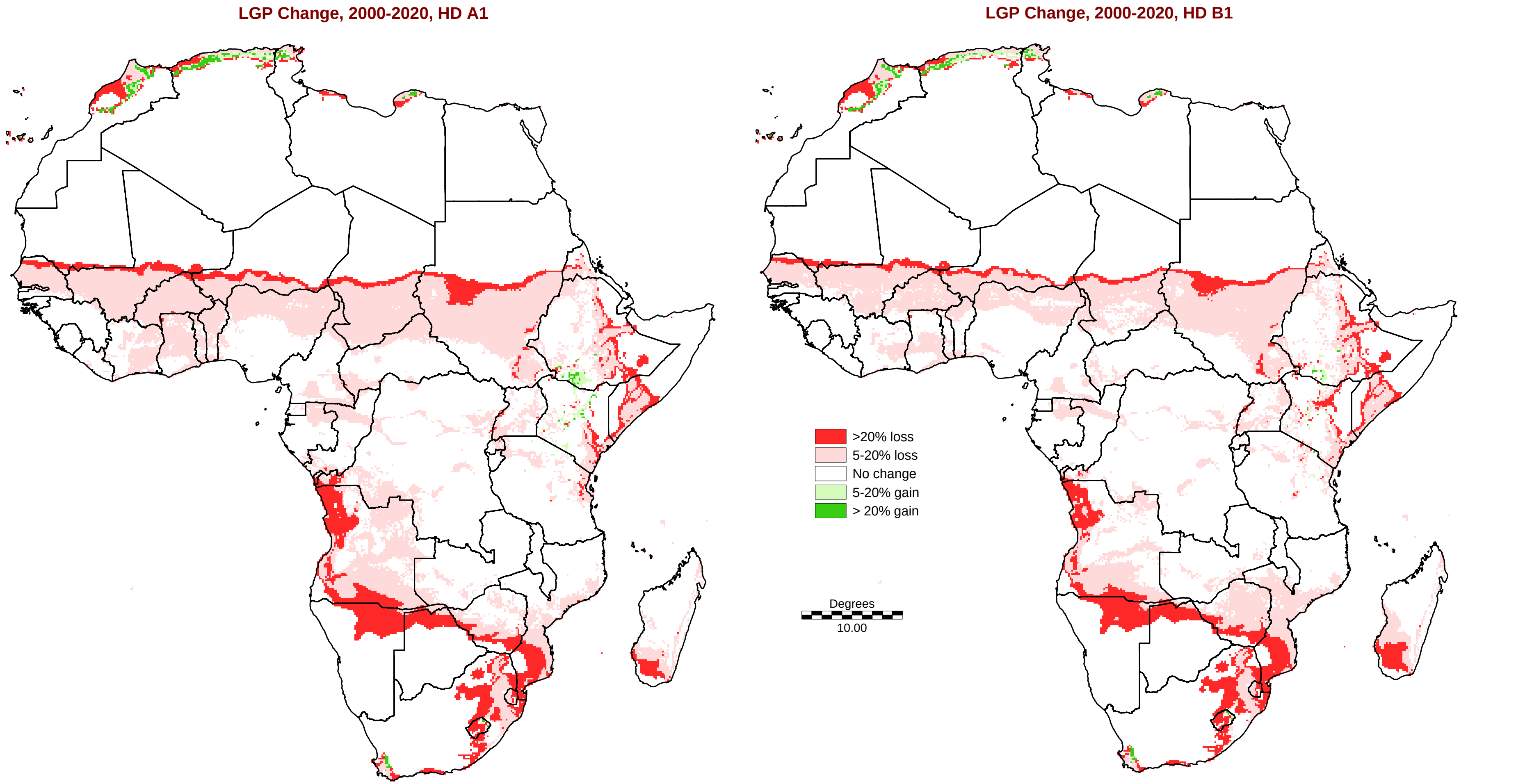

Figure 8 (B). Percentage changes in length of growing period to 2020, HadCM3 and scenarios A1F1and B1

wetter conditions, leading to higher evapo-transpiration rates and a reduced growing season. This highlights the fact that using a snapshot approach to look at trends from one time period to another is useful, but it may miss subtleties that could have profound, relatively localised impacts on livelihood strategies. This point is discussed in detail below.

For the next stage in the analysis, percentage changes in length of growing period to 2020 and 2050 were then overlaid with a relatively coarse agricultural systems classification. This was felt to be appropriate, given the sustainable livelihoods approach that was taken in this study – i.e., in recognition of some of the strategies that are being employed by households in particular places, related to uses of natural resources.

The systems classification that was used is based on that of Seré and Steinfeld (1996), whose methods were built on the agro-ecological zone concept used by FAO. The system breakdown has four production categories: landless systems (typically found in peri-urban settings), livestock/rangeland-based systems (areas with minimal cropping, often corresponding to pastoral systems), mixed rainfed systems (mostly rain-fed cropping combined with livestock, i.e. agro-pastoral systems), and mixed irrigated systems (significant proportion of cropping uses irrigation and is interspersed with livestock). All but the landless systems are further disaggregated by agro-ecological potential as defined by the length of growing period. The classification was mapped (see Thornton et al., 2002; Kruska et al., 2003) using various data sets: human population density layers for Africa for the year 2000 (modified from the Africa Population Database, version 3 of Deichmann (1996)), the United States Geological Survey's Land Use/Land Cover System database and legend (Anderson et al., 1976; Loveland et al., 2000), length-of-growing-period surfaces (Fischer et al., 2000; Jones, 1987; Jones and Thornton, 1999; IWMI, 1999), a global coverage of the irrigated areas (Döll and Siebert, 2000), and the Night-time Lights of the World database (NOAA/NGDC, 1998).

New data sets and modified techniques have been used to update this classification system, and version 3.1 of the mapped classification (Kruska, 2006) was used in this work. The modifications include the following:

- Land-use/cover: we now use version 3 of the Global Land Cover (GLC) 2000 data layer (JRL, 2005). For Africa, this included irrigated areas, so this is used instead of the irrigated areas database of Döll and Siebert (2000).

- For human population, we now use new 1-km data (GRUMP, 2005).
- For length of growing period, we use a layer developed from the WorldCLIM 1-km data for 2000 (Hijmans et al., 2004), together with a new "highlands" layer for the same year based on the same dataset, using similar methods as those outlined above.
- Cropland and rangeland are now defined from GLC 2000, and rock and sand areas are now included as part of rangelands.
- The original LGP breakdown into arid-semiarid, humid-subhumid and highland-temperate areas has now been expanded to include hyper-arid regions, defined by FAO as areas with zero growing days. This was done because livestock are often found in some of these regions in wetter years when the LGP is greater than zero (e.g. the Turkana region in north-west Kenya).
- Areas in GLC 2000 defined as rangeland but having a human population density greater than or equal to 20 persons per km^2 as well as a LGP greater than 60 (which can allow cropping) are now included in the mixed system categories.

The landless systems still present a problem, and are not included in version 3 of the classification. Urban areas have been left as defined by GLC 2000.

Because the Seré and Steinfeld (1996) classification is livestock-based, the classification was expanded to include other important communities whose livelihoods are not dependent on livestock. This involved using the FAO farming systems classification outlined in Dixon and Gulliver (2001), which itself is based on a principal livelihoods approach and has been used to assess general trends in the poverty levels associated with each system in the coming decades. The classification itself is based on FAO data and expert knowledge, and was considered not entirely "mappable" from driver variables in global- or continental-level data sets. An extended systems classification was created by overlaying version 3 of the Seré and Steinfeld classification with the FAO classification, and from those areas that were classified as "other" (i.e., non-livestock systems), we used five new categories from the FAO system:

- Coastal artisanal fishing-based systems (principal livelihoods include marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, and off-farm work);
- Forest-based systems (cassava, maize, beans, cocoyams);
- Highland perennial-based systems (Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, and off-farm work);

- Rice-tree crop systems (rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work);
- Tree crop systems (cocoa, coffee, oil palm, rubber, yams, maize, off-farm work).

The root crop systems and the cereal-root crop mixed systems were combined into one category, and combined this with the other areas that were still not classified. This category is referred to as “other” in the analysis below, although it should be understood to include these root-based systems. As might be expected, given the very different ways in which the two classifications were derived, there are some mismatches between them, in terms of areas that are classified inconsistently. Thus, for example, the coastal artisanal fishing system has goats and poultry (Dixon and Gulliver, 2001), although in our mapping of the Seré and Steinfeld system, these are classified as systems with no livestock. Overall, however, given the continental scale of these data sets, the matching between the two systems was found to be rather consistent, and for our purposes here, we deemed it appropriate to use the resulting map, which is shown in Figure 9. The systems are tabulated in Table 3, together with codes used in subsequent tables.

The LGP change classes were then overlaid on the systems layer. The results are tabulated in Tables 4-7, for the four combinations of GCM and scenario (ECHam4+A1, HadCM3+A1, ECHam4+B1, HadCM3+B1). To summarise the data, two categories were assigned. A “2” was given to a system within a country where substantial losses greater than 20 percent in LGP to 2050 are indicated, over at least half the geographic area of the system in that country. A “1” signifies moderate losses of 5-20 percent in at least half the area of the system in the country. Areas where no change is indicated are omitted from these tables, as are the (few) areas where increases in LGP are indicated; it is not that such areas are not important, but the implications are somewhat different compared with areas where loss in LGP is projected.

In the A1F1 world (Tables 4 and 5) , both the HadCM3 and ECHam4 models agree on hotspots of change in the coastal systems of southern and eastern Africa, and to a more limited extent the central West African coast. Relatively large changes are projected in some

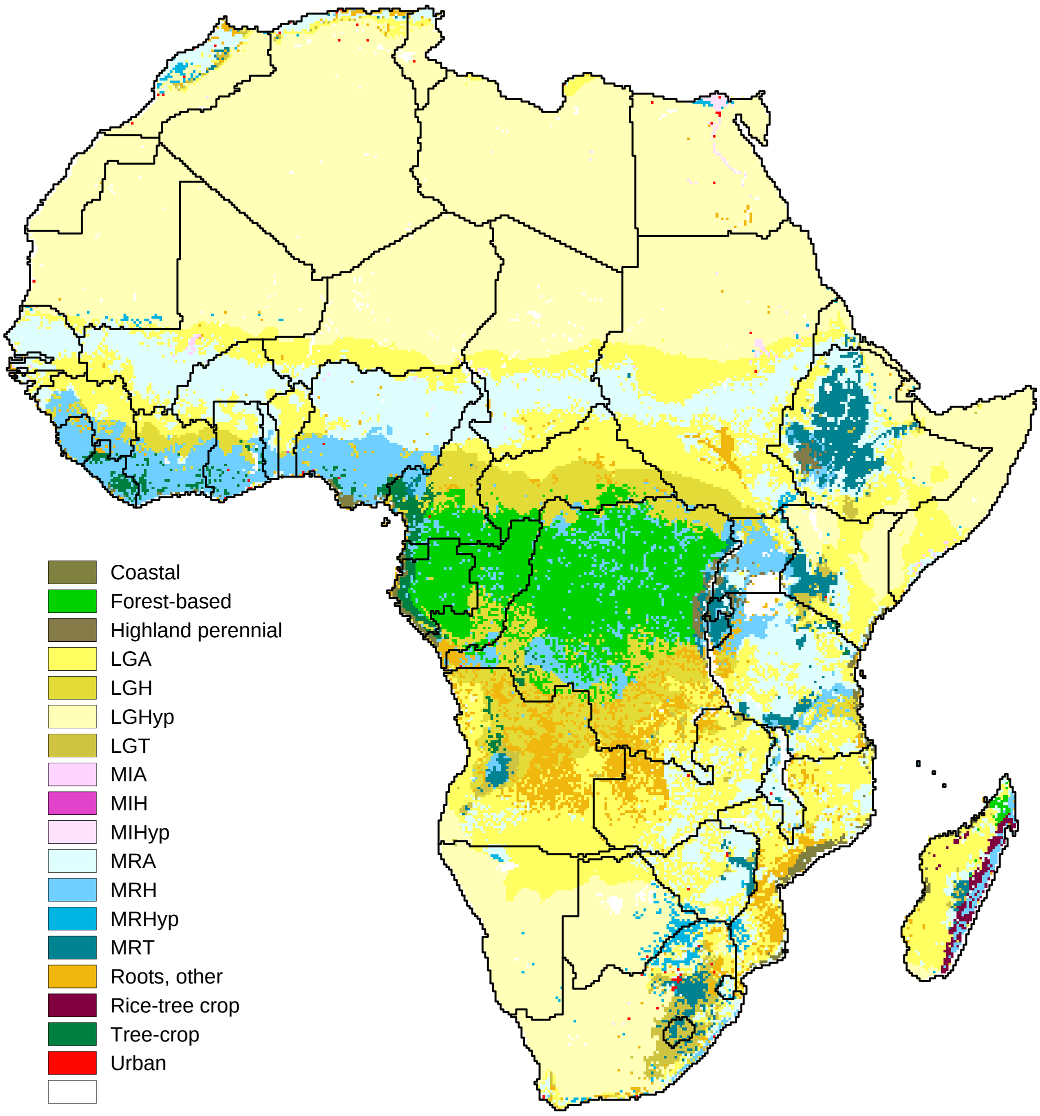

Figure 9. Farming/livelihood systems classification for Africa, based on Seré and Steinfeld (1996), Kruska (2006), Dixon and Gulliver (2001)

Table 3. System codes used in the results tables

Code	Short System Description
COAST	Coastal artisanal fishing-based systems
FORST	Forest-based systems
PEREN	Highland perennial-based systems
LGA	Livestock only systems, arid-semiarid
LGH	Livestock only systems, humid-subhumid
LGHYP	Livestock only systems, hyper-arid
LGT	Livestock only systems, highland/temperate
MIA	Irrigated mixed crop/livestock systems, arid-subarid
MIH	Irrigated mixed crop/livestock systems, humid-subhumid
MIHYP	Irrigated mixed crop/livestock systems, hyper-arid
MRA	Rainfed mixed crop/livestock systems, arid-semiarid
MRH	Rainfed mixed crop/livestock systems, humid-subhumid
MRHYP	Rainfed mixed crop/livestock systems, hyper-arid
MRT	Rainfed mixed crop/livestock systems, highland/temperate
OTHER	Other systems, including root-crop-based and root-based mixed
RITRE	Rice-tree crop systems
TREEC	Tree crop systems
URBAN	Built-up areas as defined by GLC 2000

of the forest systems, although these are systems with long growing periods. There may be LGP reductions in the perennial systems in East Africa. The arid-semiarid livestock only systems are affected throughout SSA, and impacts may be heavy in the Sahel. The humid-subhumid livestock system impacts are also quite widely distributed, again with some concentration in West Africa. There is not as much agreement between the GCMs in terms of impacts on the highland/temperate livestock systems, although moderate impacts on LGP are indicated quite widely. For the mixed irrigated systems, again the arid-semiarid systems are likely to be affected (with impacts on water availability and water-use efficiency). For the mixed rainfed systems, there is good agreement between the GCMs in terms of impacts on the arid-semiarid systems, which are likely to be widespread and substantial. There is less agreement in terms of the humid-subhumid and highland/temperate systems, although for the

Table 4. Country-by-system breakdown of LGP change class to 2050: ECHam4, Scenario A1

EC A1	COAST	FORST	PEREN	LGA	LGH	LGHYP	LGT	MIA	MIH	MIHYP	MRA	MRH	MRHYP	MRT	OTHER	RITRE	TREEC	URBAN
Angola		1		2	2		1				2	2		1	1		2	
Benin	2			2	2				2		2	2			2			
Botswana				2							2							
Burkina Faso				2	2						2				2			
Burundi											2	1		1	1			
Cameroon	1	2		2	1		1				2						1	2
Cent Afr Rep		1		2	1						2	1			1			
Chad				2				2			2				2			
Congo	1	1			1							1			1		1	1
DR of Congo		1		1	1		1				1	1		1	1		1	2
Cote D'Ivoire	2			2	2						2	2			2		1	
Djibouti																		
Equatorial Guinea																		
Eritrea				2							2			2				
Ethiopia			1	2	1		2					1		1				
Gabon	1	1			1							1			1		1	1
Gambia				2							2				1			
Ghana	1			2	2						2	2			1		1	2
Guinea Bissau				1				1			1				1			
Guinea	1			1	1			1			1	1			1		1	
Kenya	2		1												2		1	1
Lesotho							2							2				
Liberia	1											1			1		1	
Madagascar	1	2		1	2		1				1	2		1	2	2		
Malawi				1	1		1				1	1		1	1			1
Mali				2				2			2				2			
Mauritania				2							2							
Mozambique	1			1	1		1				1	1		1	1			
Namibia				2							2							
Niger				2				2			2				2			
Nigeria				2	1			2	1		2	1			1			
Rwanda											2	2						
Senegal	1			2				1			2				1			
Sierra Leone					1							1			1		1	
Somalia				2				2			2				2			
South Africa				2	2						2	2		2				2
Sudan				2	1			2			2	1		2	2			
Swaziland				2			1				1			1	2			
Tanzania	2		1	1	1		1				1	1	1	1	1		2	
Togo				2							2	2			2		1	
Uganda			1				2					1		1	1			
Zambia				1	1		1				1	1		1	1			1
Zimbabwe														1	1			1

“2” signifies substantial losses (>20%) in at least 50% of the system in that country, “1” signifies moderate losses (5-20%) in at least 50% of the system.

Table 5. Country-by-system breakdown of LGP change class to 2050: HadCM3, Scenario A1

HD A1	COAST	FORST	PEREN	LGA	LGH	LGHYP	LGT	MIA	MIH	MIHYP	MRA	MRH	MRHYP	MRT	OTHER	RITRE	TREEC	URBAN
Angola		1		2	2		1				2	2		1	1		2	
Benin	2			2	2				2		2	2			2			
Botswana				2							2							
Burkina Faso				2	2						2				2			
Burundi											2	1		1	1			
Cameroon	1	2		1	1		1				2	1		1	1		1	2
Cent Afr Rep		1		1	1						2	1			1			
Chad				2				2			2				2			
Congo	2	2			1							2			2		2	2
DR of Congo		1	1	1	1		1				1	1		1	1		1	2
Cote D'Ivoire	2			2	2						2	2			1		1	
Djibouti																		
Equatorial Guinea															1			
Eritrea				2							2							
Ethiopia			1		1							1		1				
Gabon	1	1			1							1			1		1	1
Gambia				1							1				1			
Ghana	2			2	2						2	2			2		2	2
Guinea Bissau				1				1			1				1			
Guinea	1			1	1			1			1	1			1		1	
Kenya	2		1	2			1					2		1	2		1	1
Lesotho							2							2				
Liberia	1											1			1		1	
Madagascar	1	1		1	1		1				1	1		1	1	1		
Malawi				1	1		1				1	1		1	1			1
Mali				2				2			2							
Mauritania				2							2							
Mozambique	1			1	1		1				1	1		1	1			
Namibia				2							2							
Niger				2				2			2				2			
Nigeria	1			2	1			2	1		2	1			1		1	1
Rwanda											2	2		2				
Senegal	1			1				1			2				1			
Sierra Leone	1				1							1			1		1	
Somalia				2				2			2				2			
South Africa				2	2		2				2	2		2	2			2
Sudan				2	1			2			2	1		2	2			
Swaziland				2			2				2			2	2			
Tanzania	2		2	1	1	1	1				1	1	2	1	1		2	
Togo				2							2	2			2		2	
Uganda			2	1	2		2				2	1		2	1			
Zambia				1	1		1				1	1		1	1			1
Zimbabwe				1			1				1			1	2			1

“2” signifies substantial losses (>20%) in at least 50% of the system in that country, “1” signifies moderate losses (5-20%) in at least 50% of the system.

latter, the highland systems in southern Africa are likely to be hotspots. As might be expected, the impacts of the A1F1 world on growing periods tend to be most marked in the more marginal areas (the arid-semiarid systems), although there are indications of other areas where model agreement suggests substantial changes also.

In the B1 world (Tables 6 and 7), as would be expected, the severity of the impacts is generally less, compared with the A1F1 world. However, the general trend of marginal areas becoming even more marginal (the arid-semiarid systems) is still apparent here. Impacts on the coastal systems are widespread but moderate rather than severe. The outlook for several areas in southern Africa in the B1 world is still for some substantial impacts in rangeland as well as in highland systems. There are also several countries in eastern and southern Africa where a moderate loss of growing days is projected across many of the systems in the country. Figure 10 shows the spread of arid-semiarid mixed systems (MRA) and arid-semiarid rangeland systems (LGA) for projected changes in LGP of at least 20% to 2050, for the HadCM3 model and the A1 and B1 scenarios.

For the positive changes on LGP, these are shown in Table 8. This shows all the countries in which at least 2% of the land area is projected to experience a positive gain in LGP (>5%) to 2050 (the actual percentage of each country's area is shown in brackets). Also shown are the systems in which these changes mostly occur. Thus for Mozambique, for example, using the ECHam4 GCM, the analysis suggests a positive impact on LGP under both the A1 and the B1 scenarios; these occur mostly in the LGA and MRA systems, in 14% of the country in an A1 world and 12% of the country in a B1 world. Such changes are not projected using the HadCM3 GCM.

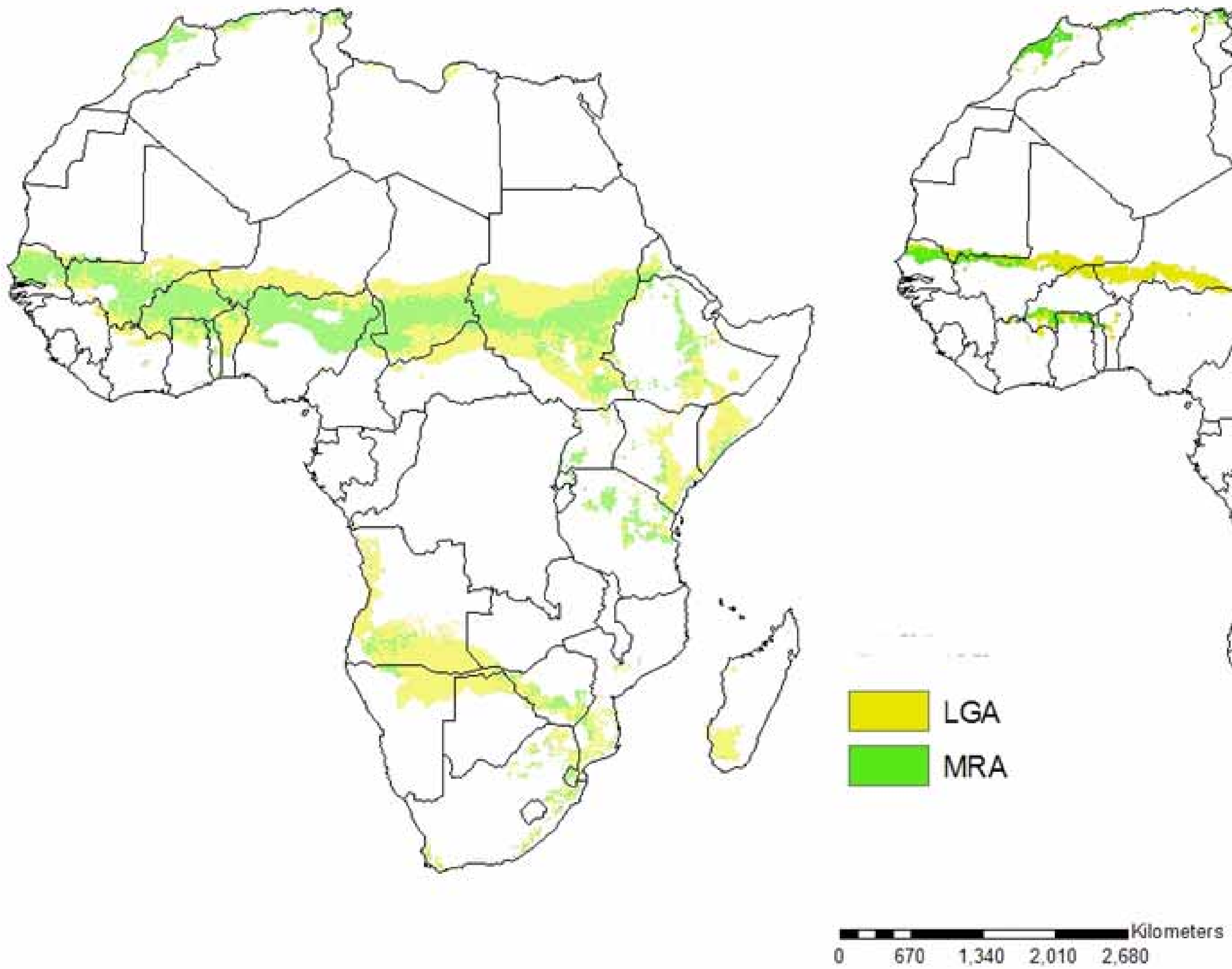

Figure 10. Areas within the LGA and MRA systems projected to undergo >20% reduction in LGP to 2050: HadCM3, A1 (left), B1 (right)

Table 6. Country-by-system breakdown of LGP change class to 2050: ECHam4, Scenario B1

EC B1	COAST	FORST	PEREN	LGA	LGH	LGHYP	LGT	MIA	MIH	MIHYP	MRA	MRH	MRHYP	MRT	OTHER	RITRE	TREEC	URBAN
Angola		1		2	1		1				2	1		1	1		2	
Benin	1			1	1				1		1	1			1			
Botswana				2							2							
Burkina Faso				2	2						1				1			
Burundi											2	1		1	1			
Cameroon		1		1							1							1
Cent Afr Rep				1							1							
Chad				1				2			1				1			
Congo	1	1			1							1			1		1	1
DR of Congo				1	1		1				1				1		1	1
Cote D'Ivoire	1			1	2						1	1			1		1	
Djibouti																		
Equatorial Guinea																		
Eritrea				2							1							
Ethiopia					1						1	1		1				
Gabon	1	1			1							1					1	
Gambia				1							1				1			
Ghana	1			1	1						2	1			1		1	1
Guinea Bissau				1				1			1							
Guinea				1	1			1			1	1			1		1	
Kenya																		
Lesotho														2				
Liberia	1											1			1		1	
Madagascar	1	1		1	1		1				1	1		1	2	1		
Malawi				1	1		1				1	1		1	1			1
Mali				2				2			1							
Mauritania				2							2							
Mozambique	1			1	1		1				1	1		1	1			
Namibia				2							2							
Niger				2				2			2				2			
Nigeria				1	1			1			1				1			1
Rwanda											1	1						
Senegal	1			1				1			1				1			
Sierra Leone																	1	
Somalia				2				2			1				1			
South Africa					2						2	1		2				
Sudan				2				2			2			1	2			
Swaziland							1				1			1	1			
Tanzania	1		1	1	1						1	1	1	1	1		1	
Togo				1							1	1			1			
Uganda			1											1	1			
Zambia				1	1						1	1		1	1			1
Zimbabwe														1	1			1

“2” signifies substantial losses (>20%) in at least 50% of the system in that country, “1” signifies moderate losses (5-20%) in at least 50% of the system.

Table 7. Country-by-system breakdown of LGP change class to 2050: HadCM3, Scenario B1

HD B1	COAST	FORST	PEREN	LGA	LGH	LGHYP	LGT	MIA	MIH	MIHYP	MRA	MRH	MRHYP	MRT	OTHER	RITRE	TREEC	URBAN
Angola		1		2	1		1				2	1		1	1		2	
Benin	1			1	1				1		1	1			1			
Botswana				2							2							
Burkina Faso				1	1						1				1			
Burundi											2	1		1	1			
Cameroon		1		1	1		1				1	1			1			1
Cent Afr Rep		1		1	1						1	1			1			
Chad				1				2			1				1			
Congo	1	1			1							1			1		1	1
DR of Congo		1		1	1		1				1	1			1		1	2
Cote D'Ivoire	1			1	1						1	1			1		1	
Djibouti																		
Equatorial Guinea															1			
Eritrea				2							1							
Ethiopia			1		1						1	1		1				
Gabon		1																
Gambia				1							1				1			
Ghana	1			1	1						2	1			1		1	1
Guinea Bissau				1				1			1							
Guinea				1	1						1	1					1	
Kenya	2		1	2			1				1	1		1			1	1
Lesotho							2							2				
Liberia												1						
Madagascar	1	1			1		1					1		1	2	1		
Malawi				1	1		1				1	1		1	1			1
Mali				1				2			1							
Mauritania				2							2							
Mozambique	1			1	1		1				1	1		1	1			
Namibia				2							2							
Niger				2				2			1				1			
Nigeria				1	1		1	1	1		1	1		1	1			1
Rwanda											1	1		1				
Senegal	1			1				1			1				1			
Sierra Leone																		
Somalia				2				2			2				1			
South Africa				2	2						2	1		2				2
Sudan				2	1			2			2	1		1	2			
Swaziland				2			1				2			1	2			
Tanzania			1			1	1				1	1	1				1	
Togo				1							1	1			1			
Uganda			1	2	1		2					1		1	1			
Zambia				1							1	1			1			1
Zimbabwe				1			1				1			1	1			1

“2” signifies substantial losses (>20%) in at least 50% of the system in that country, “1” signifies moderate losses (5-20%) in at least 50% of the system.

Table 8. Positive LGP changes to 2050: countries with >2% of the land area in change classes 4 and 5 (>5% positive gain) and the systems where this mostly occurs, under two scenarios using two GCMs

	Scenario A1		Scenario B1	
	ECHam4	**HadCM3**	**ECHam4**	**HadCM3**
Ethiopia	LGA MRA MRT (3%)	LGA LGT (3%)	LGA MRA MRT (5%)	
Kenya	LGA LGT MRT (5%)		LGA LGT MRT (26%)	
Lesotho	LGT MRT (5%)	LGT MRT (5%)	LGT MRT (7%)	LGT MRT (6%)
Mozambique	LGA MRA (14%)		LGA MRA (12%)	
Nigeria	MRH (3%)			
Swaziland			MRA (11%)	
Uganda	LGH MRH MRA (5%)		LGA MRA (13%)	
Zimbabwe	LGA MRA (26%)		LGA MRA (11%)	

System codes as in Table 3. Percentages in brackets show the proportion of each country where positive LGP changes are projected to occur. Thus for Mozambique, for example, ECHam4 projects positive impact on LGP under both the A1 and the B1 scenarios; these occur mostly in the LGA and MRA systems, in 14% of the country in an A1 world and 12% of the country in a B1 world.

The results of the analysis of number of growing seasons in Africa is shown in Figure 10, for current conditions and using the HadCM3 model and the A1 scenario. There are a very small number of pixels that register three valid seasons from time to time (as defined in section 4.1); most are in coastal West Africa and a few are in Kenya. There appears to be some bimodality in some years in a wide range of inter-tropical African climates (Figure 10). Dependence on average climate normals clearly can give a highly misleading picture of what actually occurs on the ground from year to year. The right-hand panel in Figure 10 shows projected changes in number of growing seasons to 2050 using the HadCM3 model and the A1 scenario (and as above, we are assuming that rainfall variability is not changing between now and 2050).

The results of using MarkSim to estimate the probability of season failure are shown in Figure 11. The left-hand panel shows the situation for current conditions, and the legend refers to the probability of main season failure (as defined above, the main season being the longest simulated, whether it in fact corresponds to the “long rains” in any place or not). The right-hand panel shows the situation in 2050 as projected using HadCM3 and the A1 scenario. The general increases in probabilities are marked, although it should be noted that this is a relatively conservative assessment for crops, and this does not say anything as to what is happening to pastures (such analyses could be done using appropriate pasture productivity indices).

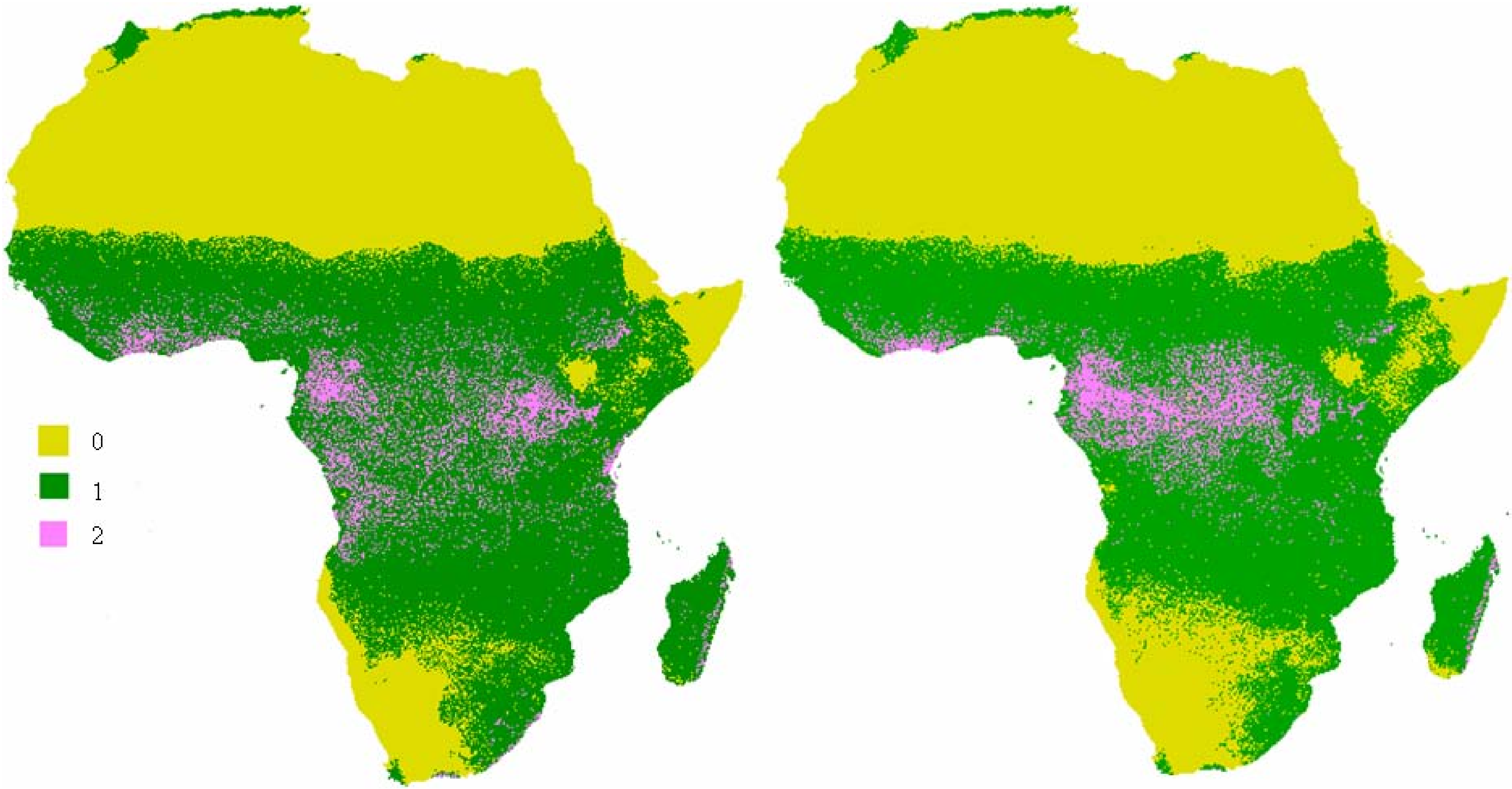

Figure11. Number of growing seasons (as defined in the text): left-hand panel, current conditions; right-hand panel, in 2050 (HadCM3, A1)

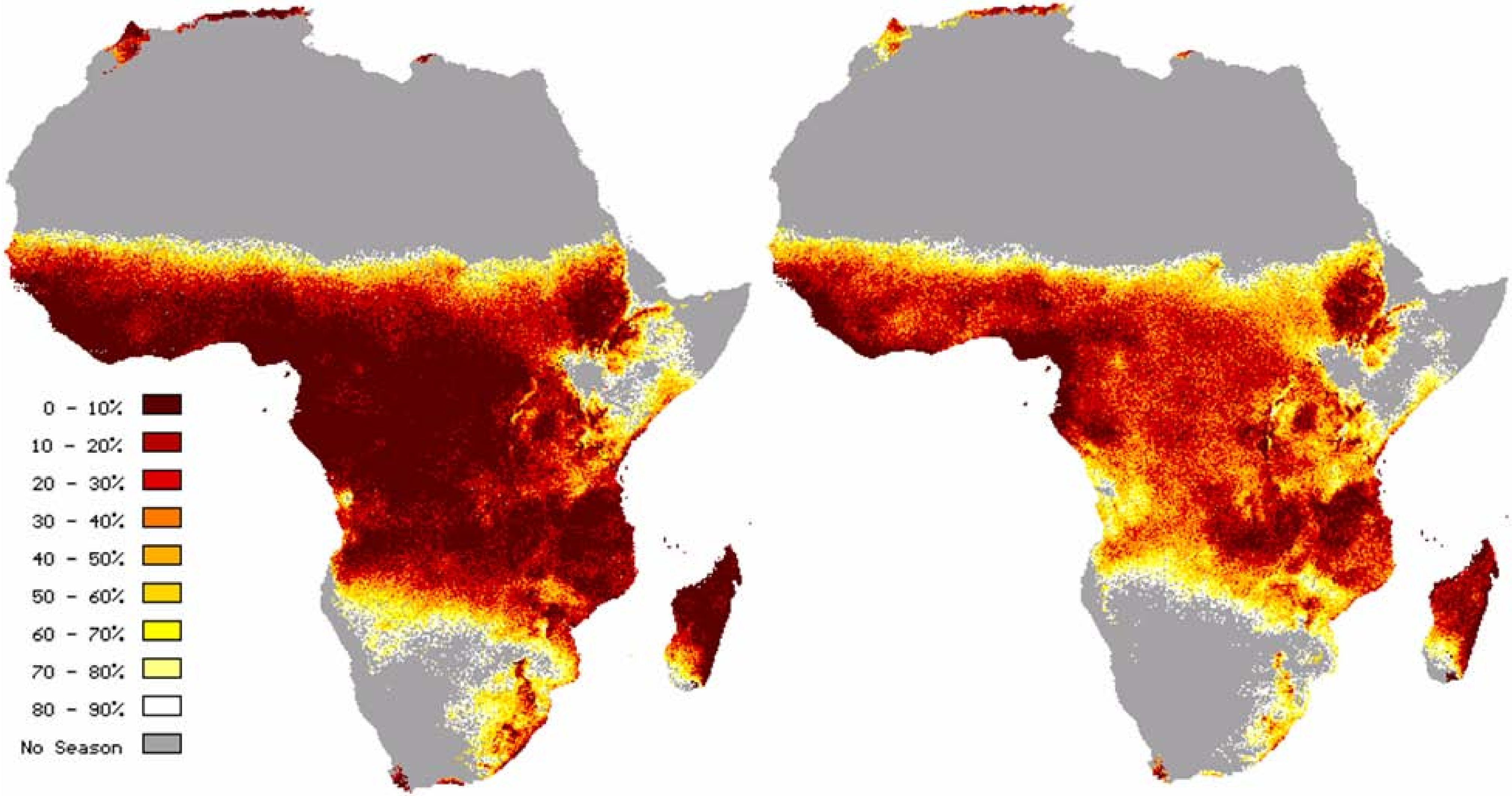

Figure12. Percentage of failed seasons (as defined in the text): left-hand panel, current conditions; right-hand panel, in 2050 (HadCM3, A1)

4.3 Uncertainties in the analysis

The analysis presented above has several uncertainties associated with it, and in addition there are some serious omissions in terms of what we have been able to include in the analysis.

There are various uncertainties associated with the GCMs themselves. The science of GCM development is continuing to develop rapidly, and there are already new generations of many of the GCMs used in this analysis (although whose output data are not yet generally available on the web). As noted above, different models have different capabilities for representing current conditions (and, by implication, possible future conditions, although of course this capability cannot be assessed now), and there are considerable uncertainties in the science of climate modeling. Regional Climate Models (RCMs) that are nested within GCMs have already been developed for some parts of Africa, and as both RCMs and GCMs improve in the future, performance should improve, although some uncertainties will always remain. As noted above, comprehensive validation work on GCMs for African conditions is needed.

Another source of uncertainty relates to the SRES scenarios used. As noted above, these have been criticized on various grounds, but at least they are internally consistent and transparent. It appears that scenario building will become an increasingly important activity in the future, and as the art and science involved improve, so should the utility of scenario analyses that can help to discover what is unknown that ought to be known before making decisions, understand the significance of uncertainties, illustrate what is possible and what is not possible, and identify what strategies might work in a range of possible scenarios (Glenn, 2006).

There are also sources of uncertainty associated with the downscaling techniques used here. Careful downscaling is crucial if the validity of results is to be preserved. In addition to the validity of the techniques used themselves, there are also key issues related to the climate grids and the quality and availability of the underlying data (Jones et al., 2005).

A further source of technical uncertainty lies in the systems classification used above. There are considerable conceptual difficulties involved in assembling meaningful systems classifications that are amenable to being mapped from primary data. Some work on this issue is being undertaken by some of the CGIAR centres with FAO, and improvements are clearly needed if useful classifications of livelihood options are to be developed, even at a regional level.

In addition to the technical uncertainties listed here, we have to acknowledge other limitations of this hot-spot analysis. It is likely that we are under-estimating the extent of climate-related hazards here, because we are not taking into account important extreme events such as droughts and flooding, nor are we directly dealing with the fact that the variability of weather patterns in many places is increasing and with it the probability of extreme events and natural disasters occurring (Kasperson and Dow, 2005). For this study, we were not able to find detailed data at the continental level that described flood and drought risk and how these could change in the future. IPCC (2001) noted that increasing attention was being paid to the analysis of extreme events in climate model simulations, and that high-resolution climate models would be needed to study them in the future.

In addition, other impacts may be expected that are not dealt with directly here. Sea-level rise will affect coastal settlements in various ways, including impacts on flooding and erosion, particularly along the eastern seaboard of southern African (IPCC, 2001b; DFID and others, 2003). The impacts on river systems may also be substantial, with decreases in run-off and water availability that may have implications for agriculture and hydropower systems.

There are thus several sources of uncertainty in the hotspot analysis outlined here, and some of these issues are discussed further below. The likelihood is that the identification of the hotspots in this study has been done in a fairly conservative manner. The results of the analysis are thus indicative only, and there are various areas in which considerably more work is required. These are also discussed below.

Poverty and Vulnerability

5. Poverty and vulnerability

The second stage of the analysis involved characterization of sub-Saharan Africa, on the same country-by-system basis as was done for the climate change impacts, in terms of a set of vulnerability indicators. As noted in Section 3, there is considerable and expanding literature on frameworks for vulnerability assessment. There have been several attempts at developing national-level indicators and indices for human aspects of vulnerability, although the trend seems to be for successive attempts to build on previous studies and to add to the complexity (Vincent, 2004). There are many methodological issues surrounding the choice, use and interpretation of indicators for vulnerability assessments, and Vincent (2004) and Brooks et al. (2005) discuss a wide range of possible problems. It is often not possible (or sensible) to use other people's lists of vulnerability indicators. For instance, Brooks et al. (2005) developed a list of eleven indicators at the national level that describe, in fairly rigorous statistical terms, vulnerability to mortality from climate-related disasters. Similarly, the list of sub-indicators that Vincent (2004) used to develop a social vulnerability index at the national level contains several sub-indicators that were applied in this study, but was not developed in the context of sustainable livelihoods and use of natural resources. Thus, an attempt was made to come up with a set of proxy indicators based on a longer list that was developed in a workshop setting, and pragmatically assess these in relation to data sources, while being guided by the reviews and experiences of others, particularly TERI (2003), Vincent (2004), Adger et al. (2004) and Brooks et al. (2005). A Principal Components Analysis was then carried out on the 14 indicators, which reduced the set to four orthogonal factors, and these were used to construct an "overall" indicator of vulnerability and systems-by-countries were then classified in quartiles. These results were then combined with the change hotspot results outlined in section 4. The results should be treated as indicative only, and we would caution strongly against over-interpretation of the results, particularly because the uncertainty associated with them is not known at this stage.

5.1 Data and analysis

A key output from the project workshop held in September 2005 was a list of possible or candidate proxies that could be used as vulnerability indicators, grouped into the five asset types associated with the sustainable livelihoods approach (Appendix 2). The list of 26 items was subsequently revised in a number of ways. First, there were data availability issues that limited our ability to include some of these indicators. For biodiversity, for example, we had access to a continent-level large mammal database (IEA, 1998), and while there are areas where this biodiversity can provide livelihood options through tourism, this did not seem to be very generalisable. Likewise, spatial data on the distribution of freshwater fish resources is still very patchy, so we have had to omit this from the list. Second, there were some indicators that were likely to be highly correlated at a continental level, and where there was likely to be some duplication between candidate proxies, such as access to communications networks and access to electricity, one was omitted. Third, there were some indicators in the list where the nature of the relationship with vulnerability is likely to be highly complex and situation-dependent. Human population density and population growth rate are two examples. A high population density could be indicative of high vulnerability, in terms of households' dependence on a decreasing supply of (or decreasing access to) natural resources; while in another situation, it could be indicative of lower levels of vulnerability through better accessibility to markets for the sale of produce and increasing household incomes.

Accordingly, the original list was revised, and the set of indicators used in the analysis below is shown in Table 9. The corresponding data layers were obtained from different sources and consisted of both raster and vector layers. The layers were all converted to raster and resampled to 18.431 km resolution. All the data sets were re-projected to Lambert Equal Area projection that maintains the integrity of areas and enables raster overlays and computation of cell statistics during the analysis. A few notes on each indicator layer follow.

There are three indicators that relate to natural capital. The first relates to **crop suitability.** This index represents the suitability of different areas to crop production based on two layers. The first layer represents soil production index, which considers the suitability of the best adapted crop to each soil's condition in an area and makes a weighted average for all soils present in a cell on the basis of the characteristics of that soil. The suitability was then ranked on a scale from 1 (least suitable) to 6 (most suitable). Areas covered by water were classified as zero. The second layer was the crop production layer, a binary layer with 1 representing areas with crops and 0 representing areas without crops. The two layers were overlaid and areas with crops reclassified to represent an increasing suitability index from 1 to 6 and areas with no crops represented by zero. The soil-crop suitability layer was obtained from FAO and the binary crop layer from GLC cropland

Table 9. Vulnerability indicators used in the analysis

	Type	Indicator	Descriptor	Hypothesised functional relationship with vulnerability	Data source
1	**Natural capital** Crop suit	Suitability for crop production	For all cropped pixels, derive the agricultural suitability (scale 1 to 8)	The higher the suitability, the higher the potential crop production, the more potential vulnerability of households to substantial changes in climate	FAO agric suitability layer GLC 2000 cropland
2	**Natural capital** Soil deg	Soil degradation due to wind, water & human-induced erosion	Four categories (low to high) of potential soil degradation	The higher the soil degradation potential, the higher the vulnerability	GLASOD
3	**Natural capital** Basin	Internal water resources by sub-basin	A measure of water resources for each pixel, from none to high in 6 classes	The more internal water, the lower the vulnerability of the household	FAO Atlas of Water Resources and Irrigation in Africa
4	**Physical capital** Mkt access	Accessibility to markets	Continuous index based on travel time to nearest urban areas	The closer to the market, the more diversified income can be and the higher the resilience to shocks, even when farm sizes are small. Better access to markets also implies better service provision	Accessibility layer
5	**Social capital** HPI	Human Poverty Index	Composite index based on probability at birth of reaching age 40; adult literacy rate; % population with no sustainable access to improved water source; % children underweight for age	Higher HPI-1 implies higher social capital available	UNDP country-level data (HDR, 2005)
6	**Social capital** Gov	Governance	Country-level data on voice & accountability, and government effectiveness	Better governance promotes foreign investment and creates more jobs. A higher index means more social capital	World Bank composite data (Kaufmann et al., 2005)
	Type	**Indicator**	**Descriptor**	**Hypothesised functional relationship with vulnerability**	**Data source**

7	**Human capital** Child 5	Stunting, poverty	% children under 5 who are stunted	Stunting is one measure of food security and a proxy for poverty	FAO sub-national data
8	**Human capital** Inf mort	Infant mortality rate, poverty	Mortality rate of infants	Higher infant mortality rates imply higher levels of vulnerability	CIESIN sub-national data
9	**Human capital** Underweight	% children underweight, poverty	% of children under 5 who are underweight for their age	Higher rates of underweight children imply higher levels of vulnerability	CIESIN sub-national data
10	**Human capital** Malaria	Malaria risk	Climatic suitability for endemic malaria	Areas with higher risk of malaria are more vulnerable	MARA
11	**Human capital** Pub hlth	Public health expenditure	Public health expenditure, as a % of GDP	Areas are less vulnerable with higher government expenditure on public health	Country-level data (HDR, 2005)
12	**Human capital** HIV	HIV/AIDS prevalence	Proportion of working population (15-49) with HIV/AIDS	Areas with higher prevalence of HIV/AIDS are more vulnerable	Country-level data (HDR, 2005)
13	**Financial Capital** GDP Ag	Agricultural GDP	Agricultural GDP as % of total GDP	Economies with higher dependence on agriculture are less diverse and more susceptible to climatic events	Country level data (World Bank, 2005)
14	**Financial Capital** Int con	Global inter-connectivity	The difference between all exports as a % of GDP and all imports as a % of GDP	Economies with higher dependence on imports are more vulnerable to climate change and extreme events	Country level data (World Bank, 2005)

Note: Variable codes are shown in red in column two

Table 9, continued

datasets (more information on this data can be obtained from http://www-gvm.jrc.it/glc2000/). The hypothesis is that vulnerability increases with an increase in crop suitability, as household livelihoods are more at risk from substantial changes in climate.

The second indicator is the **severity of human-induced degradation**. The Global Assessment of Human Induced Soil Degradation (GLASOD) (1990) by the International Soil Reference and Information Centre (ISRIC), currently World Soil Information, is the first world-wide assessment of soil degradation and is currently the only uniform global source of land degradation data (FAO, 2000). In this data set, the severity of human-induced wind and water erosion is indicated by a combination of the degree and the relative extent of the degradation process. The erosion categories were reclassified into six major classes of degradation, light, moderate, severe, very severe, none and not classified. Numerical indices were assigned to represent these values for each pixel. These data were obtained from www.isric.org. The assumption here is that the higher the human-induced soil degradation potential, the higher the vulnerability of the household.

The third indicator relating to natural capital is the extent of **internal renewable water resources** (IRWR). This represents the renewable water within a sub-basin (of which there are some 600 in Africa) in cubic mm per year. These data were developed by FAO using a model that uses a range of information, including regional coverages of the main climatic elements of the water balance (precipitation, potential evapo-transpiration), soil properties, and/or irrigation. The model is divided into two parts: a vertical soil-water balance model, performed monthly for every grid cell (10 km × 10 km) that computes the part of precipitation which does not return to the atmosphere through evapo-transpiration. This "surplus" water is then routed through the landscape in the rivers by the horizontal part of the model. This is done by generating a grid-based hydrological network based on a digital elevation model. The ultimate output expresses the difference between the natural outflow and the natural inflow calculated by the model and represents the sub-basin contribution to the overall runoff of the major basin. In cases where the natural outflow is less than the natural inflow, IRWR is zero. These data were obtained from http://www.fao.org/landandwater. The assumption is that the more internal water available in the landscape, the lower the vulnerability of the household.

One indicator of physical capital is included: **accessibility to markets**. This is a continuous index, and is calculated on the basis of two inputs: a road network with a “travel time” associated with each road arc, and a map of populated places. For each node on the road network, accessibility potential is calculated based on the weighted population of the nearest populated places on the network. The weights are based on the travel time to the nearest market centres. The index represents the relative accessibility to markets for every pixel in the study area. More information on these data can be obtained at http://grid2.cr.usgs.gov/globalpop/africa/Africa_index.html (the author is A Nelson, based on previous documentation and methods in Deichmann (1996)). From a livelihoods perspective, the assumption here is that the closer a household is to the market, the more diversified household income sources can be. The household is also likely to have better service provision.

For social capital, we used two indicators. One is the **human poverty index for developing countries (HPI-1**). This measures deprivation in the three basic dimensions of human development captured in the Human Development Indicator (HDI):

- The probability of death at a relatively early age, measured by the probability at birth of not surviving to age 40;
- Exclusion from the world of reading and communications, as measured by the adult illiteracy rate;
- Lack of access to overall economic provisioning, as measured by the unweighted average of two other indicators: the percentage of the population without sustainable access to an improved water source, and the percentage of children under weight for age.

Details of HPI-1 are given in the HDR (2005), and data are at a national level. The assumption here is of a linear inverse relationship between HPI-1 and vulnerability.

The second indicator of social capital relates to **governance**. Kaufmann et al. (2005) present national indicators for six dimensions of governance: voice and accountability; political instability and violence; government effectiveness; regulatory quality; rule of law; and control of corruption. Their indices are based on several hundred individual variables measuring perceptions of governance drawn from many data sources. Each indicator is normally distributed with a mean of zero and standard deviation of unity. These six indicators cannot meaningfully be averaged for a particular country, so following Brooks et al. (2005), we took two of the six (voice and accountability, and government effectiveness) and assigned the scores to quintiles, averaged the quintile scores and then rearranged these into new quintiles. “Voice and accountability” includes several indicators that measure various aspects of the political process, civil liberties and political rights, together with the independence of the media. “Government effectiveness” combines information on the quality of public service provision, the quality of the bureaucracy, the competence of civil servants, the independence of the civil service from political pressures, and the credibility of the government's commitment to policies.

The next three indicators are related to human capital, and have also been used as proxies for poverty. These are rates of chronic under-nutrition at national and sub-national levels using **stunting in growth among children under five years of age** as an indicator. Stunting is defined as height-for-age below minus two standard deviations from the international growth reference standard (National Center for Health Statistics/World Health Organization). "This indicator reflects long-term cumulative effects of inadequate food intake and poor health conditions as a result of lack of hygiene and recurrent illness in poor and unhealthy environments. The prevalence of chronic under-nutrition is generally seen as a better indicator of endemic poverty than estimates of per capita income. Stunting has a negative impact on the intellectual and physical development of children, compromising the development of human resources in poor countries. Persistent high prevalence of stunting among children indicates chronic failure in poverty alleviation" (taken from the Poverty Mapping website at www.povertymap.net). The sub-national data set assembled by FAO
using data from several sources was used.

Another indicator used was **infant mortality**. This indicator is derived by dividing the number of babies who die before their first birthday by the number of live births in that year, and multiplying by 1,000. Infant mortality represents an important poverty indicator. The sub-national data set from the Socioeconomic Data and Applications Center (SEDAC) at CIESIN (Center for International Earth Science Information Network) was used. In this data set, the infant mortality rate is defined here as the number of children who die before their first birthday for every 10,000 live births -- the standard data format of deaths per 1,000 live births is multiplied by 10 in order to preserve precision in an integer grid.

Another indicator was used, that estimates the percentage of children under 5 who are underweight for their age. **Wasting** indicates current acute malnutrition and refers to the percentage of children under 5 years of age weight-for-height is less than two standard deviations from the median weight-for-height from the international growth reference standard (National Center for Health Statistics/World Health Organization). The sub-national data set from CIESIN was used for this indicator. This dataset shows children underweight per thousand children. As for the infant mortality data set, the standard data format of percentage of children underweight is multiplied by 10 in order to preserve precision in an integer grid. For the stunting, infant mortality and wasting indicators, the hypothesis is of a direct relationship between vulnerability and these indicators.

An indicator of **malaria** was used. For this, we used the MARA (1998) map, which is a theoretical model based on available long-term climate data. It has a resolution of about 5 x 5 km. This map is not based on actual malaria data, but shows the theoretical suitability of local climatic conditions for, and therefore the potential distribution of, stable malaria transmission in the average year. It should be noted that malaria transmission can vary substantially from one year to the next, as a result of climatic conditions and malaria control activities. The MARA map shows Africa in terms of this suitability, and where climate is suitable, malaria is very likely to be endemic. Of course, "suitable" areas may have little or no malaria because of malaria control. Where climate is "unsuitable", malaria is likely to be epidemic or absent. Again, some "unsuitable" areas may have endemic malaria because of the presence of surface water in an area where there is little or no rain. In the marginally suitable areas, transmission may occur at steady but low levels (such as in eastern Africa), or in strongly seasonal cycles with great inter-annual variation (such as in West and southern Africa). Areas with higher risk of malaria are assumed to be more vulnerable.

Another indicator of human capital that was used was related to **public health expenditure**. Country-level data from HDR (2005) were used, and these figures represent the current and capital spending from central and local government budgets, external borrowing and grants (including donations from international agencies and NGOs) and social (or compulsory) health insurance funds, on health, expressed as a percentage of the country's GDP. The assumption here is that the higher the health expenditure as a proportion of GDP, the lower the vulnerability.

One more indicator of human capital was used: the **prevalence of HIV/AIDS**. Again, country-level data from HDR (2005) were used, and these refer to the percentage of people ages 15-49 who are infected with HIV. The assumption here is that areas with higher rates of HIV/AIDS are more vulnerable. Drimie (2002) states unequivocally that HIV/AIDS is "… the major development issue facing sub-Saharan Africa". The epidemic deepens poverty, reverses human development achievements, worsens gender inequalities, erodes the ability of governments to maintain essential services, reduces labour productivity and supply, and puts a brake on economic growth (R Loewenson and A Whiteside (2001), cited in Drimie, 2002).

The HIV/AIDS issues concerning land use relate to reduced accessibility to labour, less capital to invest in agriculture, and less productive households, as well as issues relate to land rights and land administration (Drimie, 2002). Note 3 (page 130) discusses climate change issues related to human health in more detail, particularly related to malaria and HIV/AIDS, and Note 4 (page 142) discusses the climate, development, and poverty nexus in Africa.

There are two indicators of financial capital. One is the **share of total GDP that is associated with agriculture**. Economies with a higher dependence on agriculture are assumed to be less diverse and thus more susceptible to climatic events and changes. Data are at national level and taken from HDR (2005). The second indicator relates to **global inter-connectivity**, and is the trade balance in terms of all goods and services exported and imported, expressed as a percentage of GDP. Economies with higher dependence on imports are assumed to be more vulnerable to climate change and climatic variability.

5.2 Characterisation of the hotspots of change

The object of this analysis was to take the hotspots of change shown in Tables 4-7 and for these, generate a set of characteristics to describe these areas in terms of some kind of vulnerability indicator. In order to distil the fourteen indicators that were identified above down to a smaller number of indicators, we decided to subject the data to a Principal Components Analysis. Because we had some data layers at national level, some at province level, and some at 10 arc-minute resolution, we pixelised all the data, whatever the resolution, and carried out PCA on all those pixels that had valid data for all fourteen indicators. PCA is an example of factor analysis, a class of statistical methods that attempts to reduce the complexity of multivariate datasets by producing a set of new factors or components that are orthogonal, thereby avoiding the problems of correlation among indicators. A disadvantage is that the new factors may not be easily interpretable. The PCA was done with a Varimax orthogonal rotation, and new factors were selected that had an eigenvalue greater than unity (SAS, 1994). Before the analysis, all indicators were transformed so that increases in their value were associated with increases in vulnerability.

The correlation matrix for the fourteen indicators is shown in Table 10. All but six of these are statistically significant at the 1% level. There is some interesting information in the correlations in Table 10. The relationships between governance, public health and the poverty proxies (stunting, wasting and infant mortality) are noteworthy. Increasing HIV/AIDS prevalence is strongly associated with increasing “public health vulnerability” (i.e., lower levels of government expenditure on public health), but apparently is negatively associated with wasting, for example. The results of the PCA in terms of the factor loadings and the percentage of variance explained by each component are shown in Table 11. The four new factors are each combinations of the fourteen original indicators, and between them these four factors explain 63% of the variance in the original dataset. Their interpretation is not straightforward, but it seems that component 1 is to do with public health expenditure and food security issues; component 2 with human diseases and governance; component 3 with HPI-1 and internal renewable water resources; and component 4 with market access and soil degradation.

To derive an “overall” vulnerability indicator, the weighted sum of the four components was calculated and the percentage of variance explained used for the weights. The resulting indicator was then normalised and the pixels grouped into quartiles. These were then aggregated into the system-by-country breakdowns of Tables 4 to 7, and for combinations of country and system where there were missing data, we used the national mean quartile across all other systems for which there were data, as a proxy for the missing system. Human development indicator data are not reported for Somalia in HDR (2005), so the country was omitted from this piece of the analysis.

The quartiles of the resulting composite indicator are mapped in Figure 13. Rather than attempting a detailed characterisation of the climate change hotspots and areas of high vulnerability (with the attendant dangers of over-intepreting the results), a qualitative synthesis was done, linking those systems in broad regions of Africa that are both vulnerable and also possibly subject to losses in LPG to 2050. The results are shown in Table 12 for two scenarios, A1 and B1, and divide the vulnerability-climate change space into four quadrants. This information was derived from inspection of three key factors: vulnerability quartiles (Figure 13); the land-based livelihood systems (Figure 9); and the projected percentage LGP changes to 2050 for different GCMs and different scenarios (Figure 8). For this synthesis, the LGP changes projected by both the HadCM3 and ECHam4 GCMs were qualitatively combined. Information on current climate variability, in terms of CV of annual rainfall, can also be qualitatively combined (estimates of the country-by-system breakdown of rainfall CV are shown in Appendix 4).

Under the A1 scenario, there are several areas that are both in the highest vulnerability quartile and may be subject to severe climate change. These include some of the MRA (mixed rainfed, arid-semiarid) systems in the Sahel; mixed rainfed systems and highland perennial systems in the Great Lakes region of eastern Africa; and LGA (rangeland, arid-semiarid) systems in parts of eastern Africa. Also in the highest vulnerability quartile in areas where moderate LGP losses are possible are the mixed systems in parts of E Africa. The areas in the second-highest vulnerability quartile that may be subject to severe climate change include the MRA and LGA systems in large parts of the Sahel; livestock systems and some mixed systems in parts of E and southern Africa; and coastal systems in E and parts of southern Africa. Other areas in the second-highest vulnerability quartile that may suffer moderate climate change include the coastal systems and tree-crop systems in parts of W Africa, forest-based systems in central Africa, and the root-based and root-mixed systems in southern parts of central Africa.

The situation under the B1 scenario is not so different. While there are fewer areas in the highest-vulnerability-severest-climate-change quadrant (Table 12) MRA systems are still affected in the Sahel, as are LGA and some mixed systems in parts of E Africa. The climate change effects on the Great Lakes region of eastern Africa are less than in the A1 scenario, but this is still a vulnerability hot-spot. The situation is similar for the areas in the second-highest vulnerability quartile that may suffer severe climate change: the coastal systems in eastern and southern Africa are still in this quadrant, as are the livestock and some mixed systems in southern Africa. Effects in the MRA and LGA systems of the Sahel are more scattered compared with the A1 scenario, but these are still likely to be important. Moderate climate change impacts and the second-highest vulnerability quartile include the forest-based systems in central Africa, as in the A1 scenario, and there are still quite large areas in the livestock and, to a lesser extent, mixed systems in southern Africa that fall in this category.

Table 10. Correlation matrix for the 14 vulnerability indicators

	Malaria	Soil deg	Pub hlth	Child 5	Crop suit	GDP Ag	HPI	Inf mort	Int con	Gov	HIV	Undweight	Mkt access	Basins
Malaria	1	-0.186	0.064	-0.085	0.111	-0.073	0.12	0.274	-0.137	0.232	-0.325	0.048	-0.15	-0.117
Soil deg	-0.186	1	-0.253	0.046	0.029	-0.108	-0.04	-0.002	0.007	0.079	-0.182	0.156	0.203	-0.009
Pub hlth	0.064	-0.253	1	-0.516	-0.103	0.784	0.347	-0.478	-0.383	-0.417	0.582	-0.769	0.145	0.002
Child 5	-0.085	0.046	-0.516	1	0.062	-0.522	-0.268	0.434	0.344	0.238	-0.128	0.648	-0.31	0.139
Crop suit	0.111	0.029	-0.103	0.062	1	-0.096	-0.078	0.112	0.054	0.108	-0.251	0.148	-0.037	-0.109
GDP Ag	-0.073	-0.108	0.784	-0.522	-0.096	1	0.54	-0.481	-0.367	-0.351	0.469	-0.642	0.198	-0.113
HPI	0.12	-0.04	0.347	-0.268	-0.078	0.54	1	-0.244	-0.316	-0.057	0.172	-0.251	0.119	0.159
Inf mort	0.274	-0.002	-0.478	0.434	0.112	-0.481	-0.244	1	0.271	0.374	-0.336	0.562	-0.243	-0.001
Int con	-0.137	0.007	-0.383	0.344	0.054	-0.367	-0.316	0.271	1	0.072	-0.042	0.418	-0.177	0.198
Gov	0.232	0.079	-0.417	0.238	0.108	-0.351	-0.057	0.374	0.072	1	-0.374	0.428	-0.177	-0.186
HIV	-0.325	-0.182	0.582	-0.128	-0.251	0.469	0.172	-0.336	-0.042	-0.374	1	-0.524	0.021	0.232
Undweight	0.048	0.156	-0.769	0.648	0.148	-0.642	-0.251	0.562	0.418	0.428	-0.524	1	-0.253	0.105
Mkt access	-0.15	0.203	0.145	-0.31	-0.037	0.198	0.119	-0.243	-0.177	-0.177	0.021	-0.253	1	-0.089
Basins	-0.117	-0.009	0.002	0.139	-0.109	-0.113	0.159	-0.001	0.198	-0.186	0.232	0.105	-0.089	1

Variable codes are shown in red in column 2 of Table 9.

Table 11. Rotated component (or “factor”) matrix derived using principal components analysis.

	Component			
	1	2	3	4
Malaria	-.149	.723	-.127	-.348
Soil deg	.155	.022	.049	.795
Pub hlth	-.822	-.240	.142	-.284
Child 5	.755	.039	.139	-.118
Crop suit	.076	.188	-.396	-.014
GDP Ag	-.823	-.145	.197	-.049
HPI	-.532	.371	.602	.102
Inf mort	.582	.424	-.072	-.192
Int con	.640	-.268	.048	-.142
Gov	.329	.607	-.137	.050
HIV	-.349	-.596	.396	-.287
Undweight	.828	.344	.030	.100
Mkt access	-.338	-.150	-.098	.628
Basins	.226	-.138	.779	-.060

Variable codes are shown in red in column 2 of Table 9.

Percentage of the variance extracted by components 1-4 is 32.1%, 12.7%, 10.4% and 7.9%, respectively, a total of 63%

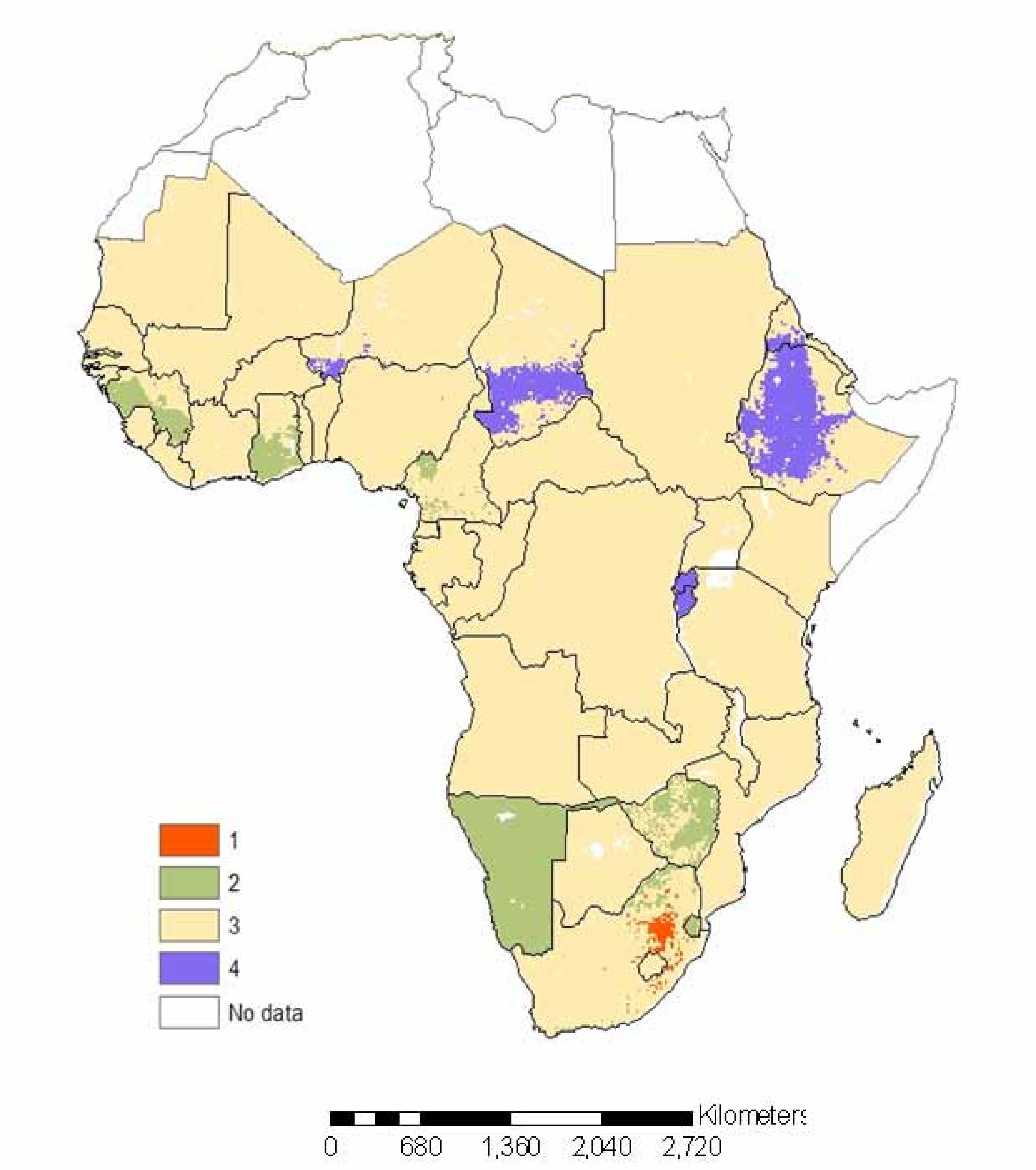

Figure 13. Country-by-systems, showing quartiles of the vulnerability indicator derived through PCA (quartile 1, “less vulnerable” – quartile 4, “more vulnerable”)

Table 12. Synthesis of possible regions and systems affected in terms of LGP loss and vulnerability quartile, for the A1 (top) and B1 (bottom) scenarios (both ECHam4 and HadCM3)

A1F1	Highest vulnerability quartile (4)	Second-highest vulnerability quartile (3)
Possibly severe LGP loss (>20% to 2050)	• Some MRA systems in Sahel • Mixed rainfed and highland perennial systems in Great Lakes region of E Africa • LGA systems in parts of E Africa	• MRA, LGA systems in large parts of Sahel • Livestock systems and some mixed systems in parts of E and southern Africa • Coastal systems in E and parts of southern Africa
Possibly moderate LGP loss (5-20% to 2050)	• Mixed systems in parts of E Africa	• Coastal systems of parts of W Africa • Tree crop systems in parts of W Africa • Forest-based systems in central Africa • Root-based and root-mixed systems in south central Africa

B1	Highest vulnerability quartile (4)	Second-highest vulnerability quartile (3)
Possibly severe LGP loss (>20% to 2050)	• Some MRA systems in Sahel • Some mixed and LGA systems in parts of E Africa	• Scattered MRA, LGA systems in parts of Sahel • Livestock systems and some mixed systems in parts of southern Africa • Coastal systems in E and parts of southern Africa
Possibly moderate LGP loss (5-20% to 2050)	• Mixed rainfed systems in Great Lakes region of E Africa • Some MRA systems in Sahel	• Forest-based systems in central Africa • Livestock systems and some mixed systems in parts of southern Africa • Mixed systems in parts of W Africa

5.3 Uncertainties in the analysis

In the climate change hotspot analysis outlined in section 4.2, there are several key uncertainties and limitations associated with the vulnerability analysis. One issue relates to the choice of vulnerability indicators. There is considerably more exploratory analysis that could be undertaken, with an even wider range of candidate vulnerability indicators, perhaps using PCA as a data reduction tool. Whether the broad vulnerability groupings derived are relatively robust or not remains to be investigated, but the PCA methodology does have the advantage of dealing with correlations between component indicators, and it seems that this is one way also to deal with data layers at different resolutions. It is likely that some of the "richness" of the component indicators is lost, however. In addition, it should be stressed that no validation work on the component indicators has been carried out. Work on these aspects is warranted.

There are several limitations with the analysis related to its coverage. One relates to the treatment of coastal areas. Agardy and Alder (2005) concluded that coastal ecosystems are among the most productive yet highly threatened systems in the world, and that they produce disproportionately more services related to human well-being than most other systems, even those covering much larger areas. They also pointed out that nearly 40% of the people in the world live within 100 km of coasts, and that coastal populations are increasing rapidly. Coastal populations are also at risk from flooding and sea-level rise, something not considered here. Nicholls (2004) used the HadCM3 model and the SRES scenarios to assess the implications of sea-level rise on changes in flooding by storm surges and potential losses of coastal wetlands through the twenty-first century. That study showed that sea-level rise increases flood impacts under all the scenarios looked at, although significant impacts are not apparent until the 2080s. Coastal wetlands are lost in all scenarios, with 5-20% loss in the A1F1 world by the 2080s, although the potential impacts on human well-being in the coastal zones from other causes are much greater than this range would suggest (Nicholls, 2004). Island states are particularly at risk from flooding. Indeed, small island states present a considerable problem for continental-level vulnerability assessments in general and in this study in particular, because the resolution of many of the data sets used is simply too coarse. This indicates that vulnerability assessments of island states need to be carried out at much higher resolutions, and probably separately from coarse-grained assessments such as this one. However, it should be added that coastal regions in eastern Africa are identified in Table 12 as climate change-vulnerability hotspots, and it is likely that the vulnerability of these regions is being underestimated here.

A related limitation of the current study is the treatment of fisheries and fresh-water aquaculture. As noted above, we were able to find little continental-scale data on fisheries and aquaculture issues. A report on a workshop convened by the Fisheries Management Science Programme noted that being able to assess the potential impacts of climate change on fisherfolk living in poverty is severely hampered by great gaps in data, by lack of understanding of the risk of impacts for fishing communities, and by lack of understanding concerning adaptation options (DFID, 2005). The report calls for a cross-sectoral approach to assess the direct and indirect impacts on such communities, something that is acknowledged to be very complex but still has to be done.

Another aspect of flooding that is not covered in this analysis are the associated health risks. Few et al. (2004) pointed out that the major direct and indirect health burden caused by floods is widely acknowledged, but it is poorly characterised and often omitted from formal analyses of flood impacts. They noted that the potential for climate change to intensify or alter flood patterns means that it is likely to become a major additional driver of future health risk from flooding. “The climate change threat heightens the need for research, both for assessment of future health burdens and for improved analysis of current and future options for health-related response” (Few et al., 2004).

Although the vulnerability analysis did include indicators related to malaria risk and HIV/AIDS, there are many other potential human health impacts of climate change on infectious diseases. (See Note 3, page 130). The impacts of changes in ecosystems on infectious diseases depend on the ecosystems affected, the type of land-use change, disease specific transmission dynamics, and the susceptibility of human populations (Patz and Confalonieri, 2005) – the changes wrought by climate change on infectious disease burdens may be extremely complex. “Tropical developing countries are more likely to be affected than richer nations in the future due to their greater exposure to the vectors of infectious disease transmission and environments where they occur” (Patz and Confalonieri, 2005). These authors conclude with a list of diseases ranked as high priority for their large global burden of disease and their high sensitivity to ecological change. For the tropics, these include malaria across most systems; schistosomiasis and lymphatic filariasis in cultivated and inland water systems in the tropics; dengue fever in tropical urban centres; leishmaniasis and Chagas disease in forest and dryland systems; meningitis in the Sahel; and cholera in coastal, freshwater and urban systems. WHO (2002) estimates that climatic changes that have occurred since the mid-1970s could already be causing over 150,000 deaths annually and about 5 million disability-adjusted life years (DALYs) per year through increasing incidences of diseases such as diarrhoea, malaria and malnutrition. Climate change is bound to have further impacts on heat-related mortality and morbidity and on the incidence of climate-sensitive infectious diseases (Patz et al., 2005), and these may be considerable.

Possible impacts of climate change on malaria distribution have been assessed in various studies. Van Lieshout et al. (2004) used the HadCM3 model and the four SRES scenarios to assess changes in areas suitable for transmission, and concluded that climate-related impacts are likely to be largest in Africa and Asia.. They also state that climate change is not likely to affect malaria transmission in the least developed countries where the climate is already highly favourable for transmission. Changes in malaria distribution in Africa have also been modelled by Hay et al (2006), again using the HadCM3 model. Their preliminary results indicated that climate change is likely to increase the numbers of people at risk of the disease, but also noted that these increases are small when compared with the likely impacts of demographic changes. In another study that looked at possible impacts of climate change on a major disease of livestock in Africa, cattle trypanosomiasis, Thornton et al. (2006b) reached similar conclusions – the demographic impacts on trypanosomiasis risk, through modifiying (generally decreasing) habitat suitability for the tsetse fly, are likely to be considerable, and these impacts may be exacerbated or moderated by climate change.

While climate change impacts may have few direct impacts on other diseases such as HIV/AIDS, climate variability impacts on food production and nutrition can affect susceptibility to HIV/AIDS as well as to other diseases (Williams, 2004). As noted in section 5.1 above, the entire area of HIV/AIDS impacts is extremely complex and wide-ranging, and it seems safe to say that considerably more work is required in this area in relation to the need to understand adaptation and policy strategies that can ameliorate these impacts and decrease vulnerability of poor households. There seems little doubt that new models for human development may well be needed in situations where the climate-poverty-institutional nexus becomes increasingly fraught, due to successive natural disasters or emergence from conflict associated with low levels of adaptive capacity (Brooks et al., 2005). Such models might contain components that draw far more heavily than hitherto on indigenous systems – for example, through conservation of local seed, which has been demonstrated in parts of East and southern Africa to strengthen community resilience in the face of successive droughts (Simms et al., 2004; S E Carter, personal communication).

User Needs

6. User needs

Recent months have seen several consultations and syntheses on researchable issues on climate change and adaptation for Africa, carried out with the support of DFID. These include the African climate report (Washington et al., 2004), the IIED-led consultation on the key researchable issues concerning climate change and development (Huq and Reid, 2005), a synthesis on linking climate adaptation (Yamin et al., 2005a; 2005b), and the synthesis of Mortimore and Manvell (2005) outlining the contributions made by projects funded under the Renewable Natural Resources Research Strategy (RNRRS) to adaptation.

Mortimore and Manvell (2005) conclude that basically the supply of new approaches and methods to assist in the management of natural resources (including adaptation) far out-strips the hard evidence of their use in the management of livelihoods: "…a whole new science of adaptation process is needed, demand-led rather than accepting the customary supply- or research-led focus". It is not easy to argue with this conclusion. For many areas of sub-Saharan Africa, however, one might be able to argue for some mitigating circumstances, given the complexity of livelihood strategies, the dynamics of the socio-economic change, and the enormity of the constraints faced by many households.

Within the context of this report, the second objective of the work was to assess the feasibility of developing a decision support toolbox for priority setting, monitoring and evaluation, that can be used to assess cross-sectoral technology, policy and management interventions aimed at improving the adaptive capacity and coping strategies of highly vulnerable households. This raises several key questions, such as which potential users are being considered, and what type of decisions might such work contribute to. What we have attempted to do here, therefore, is to contribute to the general discussion on user needs, through a survey of potential users of vulnerability-related climate change information. designed and administered by a partner who has been closely associated with several regional scoping studies (ACTS). We also refer to other studies that looked at general needs in information and capacity building related to the information produced through a much more comprehensive activity than was possible here. The survey and its results are outlined in section 6.1, followed by a discussion in section 6.2 of a comprehensive decision support toolbox for ex ante assessment of research and intervention impacts on household vulnerability.

6.1 A survey of information needs of potential users of vulnerability data

A total of twenty-one questionnaires out of thirty-five sent were received from respondents from different institutions that conduct research on climate change or are engaged in scientific or development work that is related to climate change in sub-Saharan African countries. The respondents were from Botswana, Ghana, Kenya, Mali, Malawi, Mozambique, Senegal, South Africa, Sudan, Uganda and Zimbabwe. The data were cleaned in Microsoft Excel and analyzed in the SPSS statistical package.

The African Centre for Technology Studies (ACTS) played a leading role in the administration of the questionnaires, as they already have a network of institutions with whom they are engaged in collaborative activities related to climate change. The questionnaires were administered by electronic mail and followed up by phone calls to expedite the process. In each institution, ACTS identified an individual whose responsibility was most relevant to the study to fill out the questionnaire. The respondents were from a variety of professional backgrounds that included research scientists, economists, food security program co-coordinators, weather forecasters, research assistants, research co-coordinators, program co-coordinators, NGO coordinators, project officers, public health officers, animal health assistants, and environmentalists. Respondents' academic qualifications ranged from certificate-level professional training to PhD degree. The shortest duration a respondent had been in a position was six months, while the longest-serving respondent had been in the position for 14 years. Data on specific interest areas were analyzed and the summaries are presented below.

Institutions' mandate and perceptions of climate change in the region

Many (47%) of the institutions covered in the study had a national mandate, which implies that they conducted their activities within their resident countries. Twenty per cent of the institutions carried out their activities at a sub-national level while 13 percent had a regional mandate with activities traversing several countries in a region. Institutions that had a community-level mandate accounted for 20 percent of all the institutions covered in the study. These included NGOs (46 %), government agencies (27%), research institutions (14%), academic institutions (9%) and development agencies (5%).

Regarding the effects of climate change on the livelihood of the people in SSA, there was a general agreement that communities in SSA have experienced the effects of climate change in one way or another. In terms of ranking, most of the respondents (17%) observed that frequent droughts were the foremost effect of climate change in their region. Increased variability in rainfall patterns was cited by the next 16 percent of the respondents, and third was reduced availability of pastures for livestock, mentioned by 15 percent. Other effects of climate change, such as faster drying up of water resources (accounting for 13%), increased frequency of crop failure (12%) and change in temperatures (12%), were also mentioned by respondents. A few (9%) mentioned increased incidence of floods and change in length of growing periods (5 %).

Institutions' major activities and climate change data sources

The main activities that the institutions covered in the study engage in are related to environmental conservation and improving farm productivity. Twenty-six percent of the institutions engage in tree planting activities, mainly aimed at curbing deforestation. Many institutions (41%) were engaged in supporting farm initiatives in crop-livestock production systems in order to bring food security measures to the region. Providing timely weather information and informing farmers on appropriate times to plant their crops was the core activity for 7 percent of the institutions. A similar proportion was engaged in constructing dams in the arid and semiarid lands to support the livestock production systems for pastoral communities. Water catchment management was the core activity for 19 percent of the institutions.

The primary source for information on climate change and vulnerability for the majority of the institutions covered in this study (56%) are national meteorological stations. The second most common source of climate change data is government ministries, which was mentioned by 20%, followed by the national bureaus of statistics (12%) and the private sector (12%). In the private sector, agricultural plantations and progressive farmers may have weather stations for monitoring basic weather variables such as temperature, wind and precipitation. This information is sometimes shared with the meteorological services, whose observation networks in Africa have been on the decline for a long time now. Some of the institutions mentioned as providing climate information included ENDA in Dakar, Senegal; the Drought Monitoring Centre (ICPAC), Nairobi, Kenya; the Climate Network Team of the World Bank, Washington DC; the World Meteorological Organization (WMO); the Southern Africa Development

Community (SADC) Early warning unit; the International Red Cross; and the Kenya Medical Research Institute. In the case of Ghana, a number of national research institutes such as the Crop Research Institute, School of Medical Sciences, Water Research Institute, Environmental Application and Technology Centre, and the Cocoa Research Institute, were all mentioned as important sources of climate information, indicating a high level of engagement in climate-related initiatives, particularly at the national level.

Decisions influenced by availability of data on climate change and climate data usage

Thirty six percent of the institutions cited the timing of planting operations and choice of crop types to be grown as the most important decisions influenced by the availability of climate change and variability data. Others mentioned the locating and timing of project activities (27%). Additional activities mentioned as being influenced by availability of weather and climate information included disease epidemic preparedness, planting of trees for environmental conservation, and construction of dams.

The frequency with which climate information is used was highly variable among the institutions. Weather data were mainly required on a daily basis by about half of all the institutions covered in the study. Usage of weather data on a monthly, quarterly and annual basis all stood at 17 percent. Long-term climate data, on the other hand, was mainly required annually by most of the institutions (46%) for long-term planning activities. Short-term forecasts were used annually by most institutions (43 %) and quarterly by 33 %. Long-term weather forecasts, however, were used annually by 44 percent of institutions, monthly by 33 percent, and quarterly by 22 percent.

Information gaps and understanding of climate change in SSA

Inadequate or poorly-maintained climate data was noted as the most important challenge faced by most institutions (60%) covered in the study. Also mentioned as being important was socio-economic data and information about national climate change processes such as the National Adaptation Programme of Action (NAPA), which many organisations think would allow them to capture the big picture rather than looking at climate separately from other systems. In terms of why institutions are not doing much on climate change, the lack of software for analysis of data on climate change and variability, weak interpretation skills for accuracy, and limited international exposure, which accounted for 10 percent each, were given as the major reasons.

On whether countries in SSA have already experienced impacts of climate change, most respondents were in agreement that countries have experienced the impacts in a number of ways, depending on ecology and livelihood strategies. Information as to what the institutions considered to be the main contributors to climate change in SSA were as variable as the choices given. Out of the seven options provided, deforestation was ranked first by 76 percent, while only 24 percent ranked it second. Burning wood for fuel was ranked second by 55 percent of the institutions and third and fourth by 15 percent each. Agricultural activities were ranked as the third contributor to climate change by 33 percent of the institutions, compared with 25 percent who ranked it fourth. Also ranked third by 50 percent of the respondents was land management activities. About 47 percent of the respondents ranked human migration as the fourth activity that contributes to climate change. About 40 percent of the institutions thought burning of fossil fuels was the fifth important cause of climate change in SSA.

Given the close linkage between deforestation and burning of biomass and fossil fuel, it is not entirely surprising that these were the most recognized causes of climate change and variability among the institutions covered in this study. The low use of fossil fuel in SSA means that the region contributes minimally to CO_2 emission despite the fact that it is one of the areas already facing many challenges associated with extreme climatic events,

The effect of climate change and variability on the livelihood of people in SSA

Most of the institutions recognized that climate change has affected the livelihoods of people in SSA mainly through increasing water constraints (50%). Increasing vulnerability of agricultural production in the form of crop failure was ranked first by 45 percent of respondents, while increases in the prices of agricultural commodities was ranked third by 33 percent. Forty four percent of the respondents recognized the loss of and/or increase in variability of livestock production as the fourth most important effect of climate change and variability on the people of SSA. The other effects that were cited include human migration (ranked fifth by 36%) and destruction of infrastructure (ranked fourth by 21%). Some 22 percent of the respondents thought that impacts of climate change on health was the third most important effect in SSA. Veld fires and drought were each recognized by 5 percent of the respondents as a problem, predominantly in southern Africa. Indeed, many countries in southern Africa already face numerous wild fire outbreaks especially during the dry season. This could worsen with climate change.

How institutions might ameliorate the negative effects of climate change and variability

Many institutions noted that dealing with the negative effects of climate change or reducing vulnerability of households, communities and ecosystems could be achieved by creating awareness and capacity building (50%). Another approach that was cited by 14 percent of institutions is direct intervention in agriculture by increasing water availability. About 21 percent of the institutions noted that improving accuracy of weather forecasts and educating users was another important approach. Construction of earth dams in arid and semi-arid lands, and making information available to sensitise and influence policy formulation, were each cited by 7 percent of institutions as other possible avenues through which they may help ameliorate the negative impacts of climate change in SSA. Research institutions have a big role to play in ensuring climate change research products reach the intended users, whether policy makers, development organisations or farmers.

How information on climate change and variability may help mitigate the negative effects of climate change in SSA

Many institutions (48%) covered in the study were of the opinion that availability of data and information on climate change and variability would increase awareness and influence policies, improve coping strategies of the vulnerable groups, facilitate education of vulnerable communities on the potential impacts of climate change on their livelihoods, and enable them to adapt better to a changing climate. Access to climate information would also improve the early warning systems for disaster preparedness. Thirty percent of the institutions noted that such information would inform governments and bring about change in policies necessary for mitigating effects of climate change. Another 17 percent said that developing appropriate technologies and policies were also necessary to mitigate climate change.

Institutional capacity needs assessment

Institutional preparedness in accessing, analyzing and interpreting climate change and climate variability data

The responses of the institutions on their preparedness in accessing, analyzing, interpreting climate change and climate variability data relating to specific attributes are shown in Table 13. Many respondents saw themselves as not being well prepared in accessing and utilizing information related particularly to incomes and prices, while the water constraints had the highest number of institutions (31%) that saw themselves as being well prepared in accessing and interpreting such information. In general, most institutions were not adequately prepared in accessing, analysing and interpreting climate change and variability data for the attributes presented in Table 13.

Institutions also mentioned specific areas in which they would like capacity to be built. The majority (70%) would be better off if their skills were to be built in the collection, analysis, interpretation and management of data specifically relating to climate change and variability, weather patterns, ecological factors, and land-use planning. Fifteen percent mentioned the need for GIS skills and facilities. Training in information technology, acquisition of computers and training in English (especially for non-English speakers) to enable professionals to understand terms in climate change, were all mentioned by 15 percent of the institutions studied. This underscores the importance of information access and the fact that information will be most useful only if presented in an appropriate and easy-to-understand format.

Information needs of the institutions

Most of the institutions consulted (64 %) recognized that lack of data on climate change and climate variability for monitoring was the most severely limiting information constraint on their activities. Twenty eight percent noted that the most-needed information was data on potential impacts of climate change on health and livelihoods. Methodological issues, including the determination of climate change and climate variability, were mentioned by 36 percent of respondents.

Table 13. Institutional preparedness on analyzing and interpreting climate change- and variability-related data

Indicators	Not well prepared (%)	Somewhat prepared (%)	Moderately prepared (%)	Well prepared (%)
Crop production data	20	30	20	30
Livestock production	26	21	42	11
Farmers well being	25	30	20	25
Incomes	39	22	28	11
Price indices	35	35	15	15
Land use change	30	8	30	25
Vulnerability	27	27	18	27
Water constraints	31	23	15	31
Human health status	19	25	41	8

Institutional collaboration and mechanisms and contributions to mitigate the effects of climate change

The majority of the institutions in the study (82%) collaborate with partners in the region on a continuous basis. The mechanisms for such collaboration were mainly through research contracts (43%), memoranda of understanding (20%), joint ventures (20%), institutional contacts and information sharing (13%).

In mitigating the effects of climate change in SSA, 91 percent of respondents felt that they contribute through their many activities in helping to mitigate the effects of climate change on the lives of people. Many (42%) contribute mainly by equipping communities with knowledge and skills on sustainable natural resources management through training, while another 33 percent contribute through information sharing and sensitising local communities (including NGOs) on climate change. Seventeen percent of those who contribute do so through policy formulation for national development, and 8 percent do so through developing strategies and appropriate technologies to reduce the negative effects of climate change.

The main end users of climate change related information

The major users of climate information identified by respondents ranged from governments to NGOs (Table 14). Governments and NGOs were ranked first by 50 and 39 percent of respondents, respectively. Policy institutions were ranked second by 47 percent of respondents and donor agencies third by 43 percent of the institutions surveyed.

Table 14. Main end-users of climate change and variability data from institutions covered in the survey

End user	Rank1 (%)	Rank2 (%)	Rank3 (%)	Rank4 (%)	Rank5 (%)	Rank6 (%)
Government	50	19	12	6	12	
NGO	39	28	17	11	6	
Donor Agencies		7	43	14	29	7
Policy Institutions	11	47	6	23	6	
Agricultural producers	12	20	27	20	20	
Pastoralists	9	9	9	36	27	9
Vulnerable communities		5				
Community based organizations					5	

Effect of climate change on resource allocation within the institutes

All the institutions covered in this study acknowledged that issues related to climate change and climate variability affect resource allocation within their institutions. This was particularly so for government and development organisations who have to redirect financial allocations and personnel to deal with climate-related disasters (46%). Twenty-five percent of the respondents also felt that climate change affects land and other natural resources and ultimately their productivity. Lack of climate information, such as short- and long-term forecasts, often leads to lack of adequate preparedness to deal with the consequences of climate variability such as drought, floods and disease outbreaks. In the event of such disasters occurring, resources are often channelled to deal with the impacts of extreme climatic events to save the lives of both humans and livestock. In the health sector, disease management funds are increasingly being used for controlling outbreaks rather than for surveillance that might allow adequate preparation and prevention of outbreaks of climate-sensitive diseases. Such is the need for climate and socio-economic data and the ability to analyse this to enable institutions and governments to prepare adequately and avoid fire fighting.

Other issues

In general, most of the institutions consulted were in agreement that education and awareness creation on climate change among governments, institutions and individuals was a necessary step in promoting adaptation to climate change in SSA, one of the poorest regions that is also likely to experience some of the most serious impacts of climate change. Information synthesis and dissemination among end-users remains a key activity, and this will only be achieved with the active involvement of all institutions working in the region. The issue of mainstreaming climate change information in combating established and emerging diseases such as HIV/AIDS, malaria and avian flu was also highlighted. The institutions noted that understanding the links between climate change and disease epidemiology may help to avert climate-related catastrophes, which seem to be on the rise.

Other studies

There are clear parallels from this small survey of institutions with the results of much larger and more sophisticated scoping studies, such as the IIED scoping report (Huq and Reid, 2005). That consultation process found that understanding vulnerability and exploring ways to enhance poor people's adaptive capacities were considered to be the highest priority for cross-sectoral research. There were some interesting insights from the study on the priorities for sectoral research in Africa. Respondents to the survey from Africa ranked agriculture and food security as the sector most likely to be affected by climate change, followed by water resources management, public health, disaster management, other natural resources, peace and security, and infrastructure. In terms of the perceived importance of various fields of research, in the African context top ranked was work on the impacts of climate change on specific sectors, followed by monitoring, assessment and institutional capacity to manage impacts of climate change, work on the impacts of climate change on the natural environment, and then (fourth equal) raising stakeholder awareness of climate change and building capacities to adapt to the impacts of climate change, and then governance and decision making processes to manage the impacts of climate change. As might be expected, NGOs, media, business and private sector and government ranked the governance and decision making processes area far higher (first, second or third) than did respondents from academic institutions.

Capacity development to conduct climate change research and to utilise the results was also prioritised in the scoping study. This had various dimensions, such as finding effective ways to promote South-South collaborative research between Asia and Africa; linking research to policy-making, with an emphasis on getting research messages to appropriate target groups; and linking research to existing local knowledge of climate related hazards and involving local communities in adaptation decision making (Huq and Reid, 2005). South-South cooperation is discussed in Note 2, page 123.

All this tends to suggest that there are considerable (possibly even daunting) research and capacity-building needs related to climate change impact assessment and adaptation decision making – made more difficult by the inherently cross-sectoral nature of the issues that have to be addressed and the society-wide impacts that are likely to occur – i.e., the range of stakeholders and institutions involved is pretty much as wide as it could possibly be. Meeting these needs in an effective way will inevitably involve some prioritisation, but it must clearly also involve as-yet unattained levels of cooperation between international, regional and national organisations.

6.2 Prospects for a decision support toolbox for assessing impacts on household vulnerability

As noted above, recent scoping studies have identified strong demand for a wide range of information relating to household vulnerability and adaptation. For example, Washington et al. (2004) discuss the need for effective communication between the supply-side and demand-side communities of climate information in Africa, and the need to work on means by which climate information can be incorporated into the livelihood strategies of potential users.

> "These studies all point towards the importance of dealing with existing climate-related sensitivities with actions that bring short term benefits but that also recognise the possibility of climate change and therefore at the very least do not increase exposure or vulnerability over the longer term" (Washington et al., 2004, p. 27).

These themes are echoed in several places from both the East and West Africa scoping studies (Huq and Reid, 2005), particularly the need for better links from knowledge to practice and better understanding of the socio-economic and political factors that can help address the needs of the most vulnerable groups in society. One of the priority issues that is identified in the IIED report is vulnerability mapping for all sectors (agriculture and food security, water, land, forests, coastal areas, fragile natural ecosystems, health), and that this work needs to be done at both the macro- and the micro-level, in the short-to-medium term (Huq and Reid, 2005, section 8, p 4). Despite this, it is acknowledged that information and the levels of knowledge on climate change impacts on these several sectors for East and West Africa is extremely patchy (generally poor to moderate only), and the situation is not likely to be very different for southern Africa.

Despite the data issue, it is clear that a multi-sectoral approach needs to be taken to vulnerability mapping and to adaptation. This presents considerable challenges, and it is appropriate to consider what is really feasible now and in the near future.

Even looking at this question just from the perspective of impact assessment tools and priority setting, the data limitations have to be acknowledged. Despite many activities around the world that seek to develop national poverty maps, for example, we are not yet quite at the stage where the CGIAR believes that poverty mapping can be used to assist in detailed research priority setting and resource allocation (Thornton, 2004). This situation could change quite rapidly, however, and increasing development and use of global datasets of sub-national poverty proxies are steps in the right direction.

There have been several recent attempts to use spatial data analysis as one key component of broader priority setting and impact assessment activities. Some examples are summarised in the accompanying Notes: the site selection process for the Sub-Saharan Africa Challenge Programme (Note 5, page 153); development domains in setting priorities for ASARECA (Note 6, page 157); an impact assessment framework for ranking food-feed research proposals for the System-wide Livestock Programme (Note 7, page 161); and a poverty targeting tool developed under the auspices of SAKSS (Strategic Analysis and Knowledge Support System), Note 8, page 165. These (and many other examples) are illustrative of the wide range of data sets and component tools that are available for priority setting and impact assessment. They are perhaps best thought of as building blocks that can be reassembled in different ways to suit the needs of what may be very different types of users.

In terms of an assemblage of tools and data sets that could be used to assess likely impacts of interventions dealing with adaptation to climate variability and climate change, there needs to be clarity concerning the ultimate users of such a toolbox. It is very unlikely that a "one size fits all" approach is feasible, but considerable creative will be needed in terms of making component building blocks of tools/data available to suit a diversity of needs, especially given the fact that such assessments need to be cross-sectoral.

A general framework that might be appropriate for targeting research implementers and managers with a view to cross-sectoral assessment is shown in Figure 14. This attempts to show the links between the various component parts of ex ante impact assessment of particular research activities. There are several ways in which such research might be framed, related perhaps to innovation systems and integrated natural resource management, for example. Such frameworks have arisen partly from acknowledging that the traditional "transfer of technology" approach of linear (and usually one-way) connections from up-stream research activities for technology generation, to adaptive research by extension services and subsequent delivery to farmers, needs to be greatly expanded to take account of the complexities and iterations and feedbacks that need to occur between al stakeholders in the research for development process. However the outcomes from agricultural knowledge, science and technology are generated, whether they are technologies, tools and methods, or policies, for example, the same basic

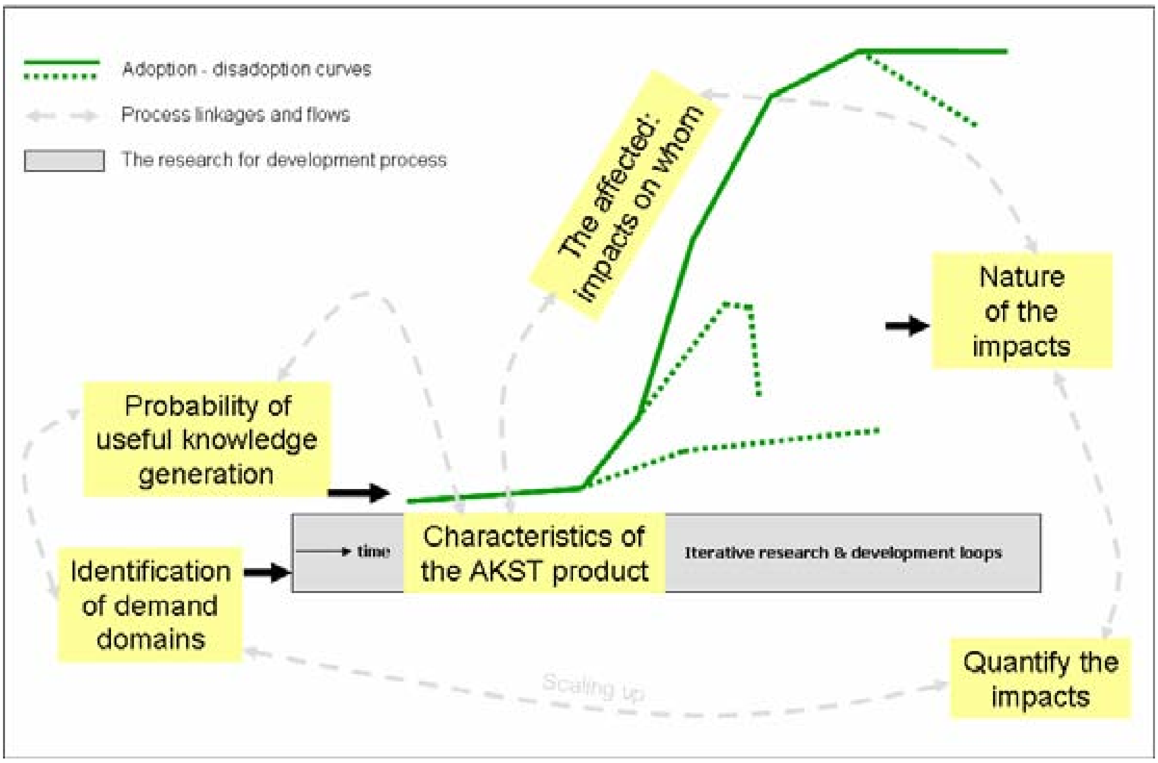

Figure 14. Stages of impact assessment of agricultural knowledge, science and technology (AKST)

steps have to be gone through in any ex ante impact assessment: where are impacts likely to be felt; who will be affected; which impacts are likely to occur; and what is the value of these intended and unintended impacts to beneficiaries and those likely to be negatively affected.

Such a framework is generic, but can be applied to particular situations in many different ways, depending on the precise purposes of the analysis and the time, resources and data available. The SLP food-feed impact assessment framework outlined in Note 7, for example, makes use of spatial data to assist users delineate demand domains and identify potential end-users, while the components related to identifying the types of impact that may result and quantifying these are much more qualitative and dependent on expert input. There is a wide range of tools available for such impact assessment work; Thornton (2006) list 18 broad tools that differ in terms of how quantitative and participatory they are, for impact assessment work in the specific context of impact assessment related to climate forecast research, although these tools can be used for impact assessments in many other contexts as well.

The kind of context that this impact assessment work would have to be embedded in is shown in Figure 15, which is slightly adapted from the conceptual framework of the International Assessment of Agricultural Science and Technology for Development (IAASTD), a large collaborative effort to assess the relevance, quality and effectiveness of agricultural knowledge, science, and technology (KST) in meeting key development and sustainability goal (information is online at http://www.agassessment.org). It shows the linkages between the indirect and direct drivers of change, and their connectedness to agricultural goods and services directly and through the medium of natural resource-related KST, and the human impacts that occur as a result.

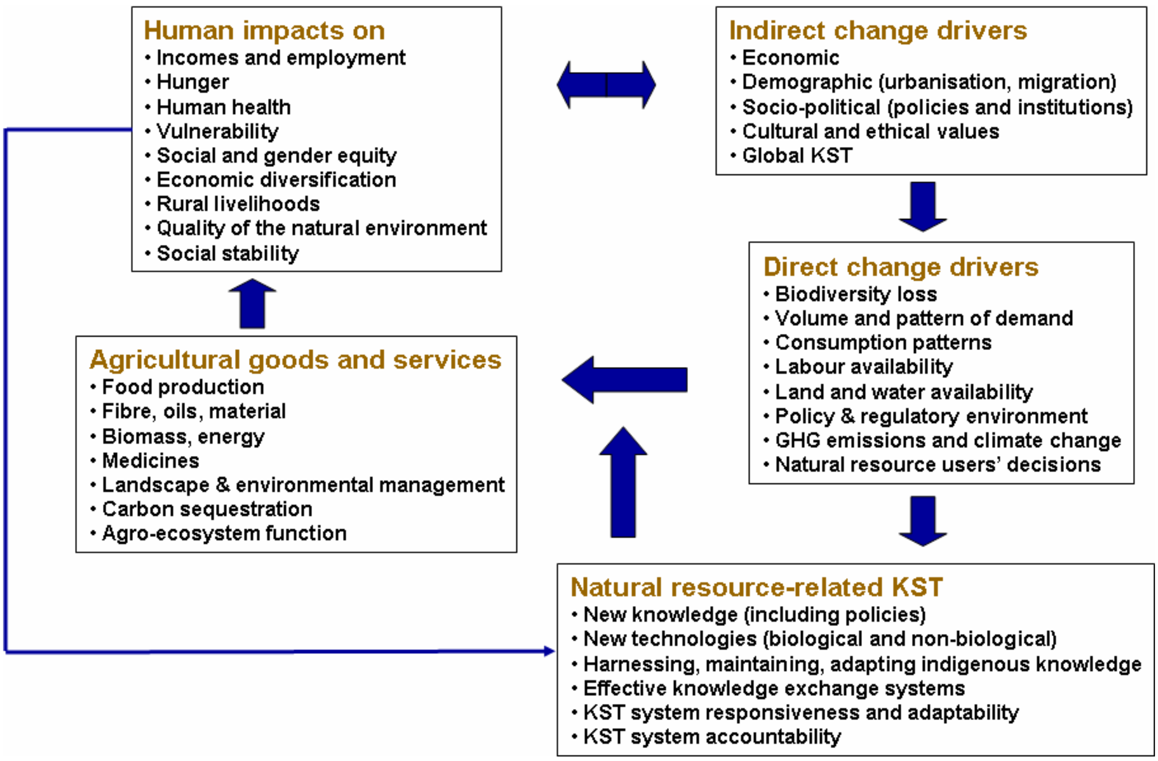

Figure 15. The conceptual framework of the International Assessment of Agricultural Science and Technology for Development (IAASTD). Source: www.iaastd.org

An ex ante impact assessment might consider one (small) piece of this complexity. Consider the situation in Figure 16, which involves assessing where a particular technology might be appropriate and what its impacts might be. Existing story lines could be used, such as those from the Millennium Ecosystem Assessment, which describe different plausible and internally consistent future states of the world in terms of economic development, demography, etc (the indirect drivers in Figure 15). Existing scenario analyses from the MEA or the IAASTD can then describe possible future states in relation to the direct drivers of change, and these scenarios then form the basis for impact assessments related to plausible future states, that might consider the possible impacts of a new technology that harnesses and builds on some aspect of indigenous knowledge (Figure 16). Spatial analysis would be used to delineate the demand domain and the target beneficiaries. In the next step, detailed crop, livestock or households could then be used to assess the impacts and quantify these in relation to particular types of household – in Figure 16, the impacts are shown in terms of food production and environmental management. Finally, the human impacts are assessed, refined and validated using household surveys, in terms of likely changes on vulnerability, household diversification, and livelihood options.

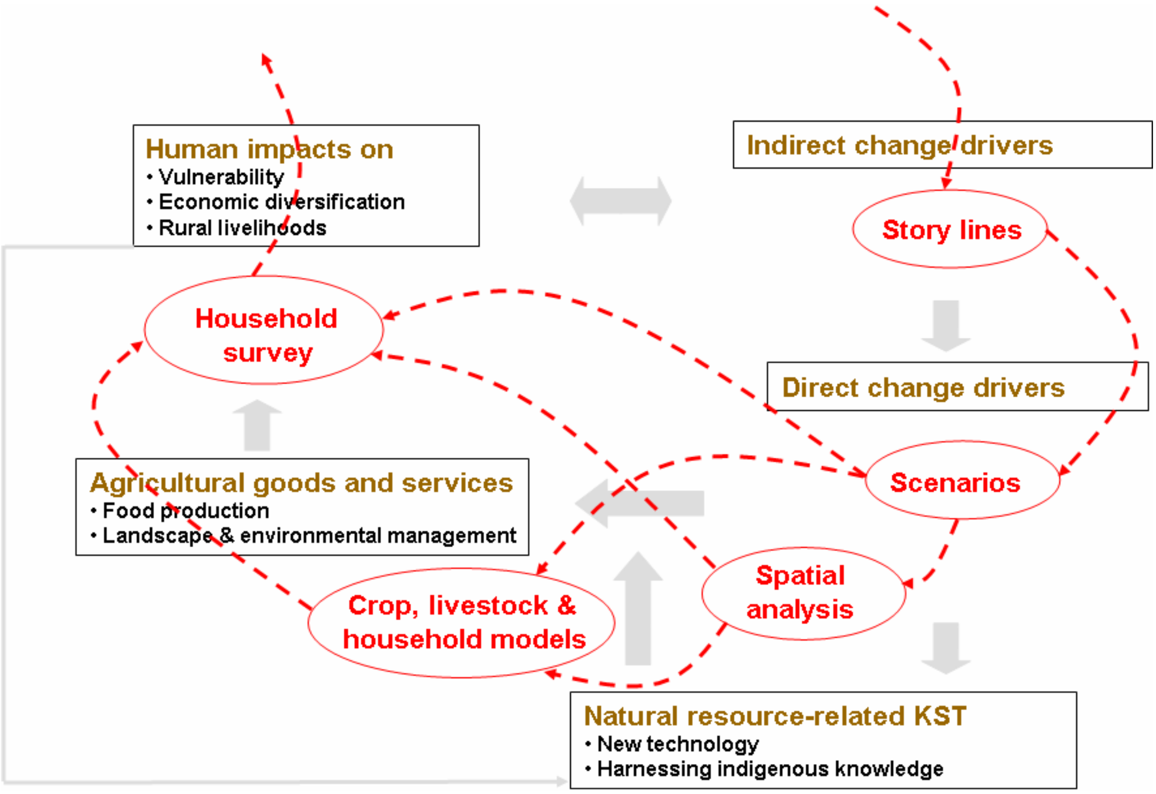

Figure 16. Applying the framework of Figure 15 to an impact or vulnerability assessment

Again, the framework is generic; the cycle of activities outlined in Figure 16 would involve a considerable amount of work, and a much quicker, more indicative impact assessment could be undertaken to look at the same issues using literature searches and expert opinion instead of modelling, spatial analysis and household survey work. For short-term impacts, scenario analysis would probably not be needed at all.

Is such an assessment system feasible in practice? There are several elements of this that exist already, although these may need further elaboration and refinement (some practical examples are described in Notes 5, 6, 7 and 8, pages 153 to 165). As noted above, considerable work has been done on developing logically consistent scenarios of possible futures, on the basis of different sets of assumptions concerning economic development and growth, population change, market integration, and technological change, for example. There has also been considerable work on combining spatial analysis with other types of livestock, crop and household models. An example is shown in Note 9 (page 168), using a variety of existing models and spatial data bases.

The kind of approach taken in this report could be refined considerably, and a toolbox containing databases, models and tools could be assembled to allow users to map out hotspots and assess vulnerability, using a much wider range of data than was done here, and even allowing users to define vulnerability in a way that suits their particular purposes. Such a "vulnerability mapping tool" might have some features in common with the open-source mapping tool developed at ILRI that is used for the SLP food-feed impact assessment framework (Note 7) and the SAKSS poverty mapping tool (Note 8). There are various aspects that would need to be addressed in putting together such a system.

First, there is the issue of baseline data. The current status of baseline data at the sub-national level is very patchy, across many sectors. The collation, maintenance and dissemination of baseline data is not an activity that is often supported by donors in the agricultural sector, for example, but in many ways it is crucial (in livestock databases, for instance, information on livestock numbers and livestock breeds is remarkably poor). While there are some collaborative efforts underway, there is a great deal more that could be done. A related issue is that of resolution. It seems clear that vulnerability has to be assessed at relatively high resolution, given the heterogeneity involved. The implications of this for data collection may be profound, however.

A second issue relates to the setting of limits to what is feasible and desirable. The breadth of the notion of vulnerability, and the breadth and complexity of the impacts that may arise, mean that there will always be limits to what can be achieved. Design and implementation have to be driven by end-user needs and requirements, and while we may not have generic systems, tailor-made systems made out of generic building blocks can surely help achieve some sort of efficiency.

Third, a recurring theme in the literature on vulnerability assessment is the need for indicators and frameworks that are transferable between situations and that other people can use. While it is unlikely that the concept of a "minimum data set", which has been developed quite successfully in relation to the modelling of certain biophysical processes, could be applied to vulnerability assessment, the development of more generic frameworks that could at least provide comprehensive guidelines to practitioners would constitute a major step forward.

Fourth, related to the third point above, is the need to take advantage of the considerable work on vulnerability assessment that has been done in the past and is being done now. There are likely to be real benefits to be gained from learning from the experience of others, particularly of other groups that have grappled with the conceptual and practical problems in developing country contexts. Vulnerability assessment would seem to be an area where there are very good prospects for productive south-south collaboration (see Note 2, page 123).

Fifth and finally, we would underline the importance and utility of incorporating the notion of "scenarios" into vulnerability assessment. While we will never have absolute knowledge of the future, scenario building and scenario analysis are key tools in helping to assess where our ignorance is positively harmful, to understand the significance of uncertainties, to illustrate what is possible and what is not possible, and to identify what strategies might work in a range of possible scenarios.

Conclusions

7. Conclusions

Climate change poses a serious, ongoing threat to development. Scholes and Biggs (2004) refer to Sub-Saharan Africa as the food crisis epicentre of the world, and conclude that projected climate change during the first half of the twenty-first century will make this situation worse. Climate change will add burdens to those who are already poor and vulnerable. At the same time, agriculture in Sub-Saharan Africa will continue to play a crucial role through its direct and indirect impacts on poverty, as well as in providing an indispensable platform for wider economic growth that reduces poverty far beyond the rural and agricultural sectors (DFID, 2005b).

The indicative results of this analysis show that many regions are likely to be adversely affected, and as noted above, in ways that have not been considered here – this is likely to be a fairly conservative assessment of hotspots and vulnerability.

In addition to highlighting various systems that may be particularly at risk, there are two key points that this work has highlighted. First, even allowing for the technical problems and uncertainties associated with climate modelling and downscaling, it is clear that macro-level analyses, while useful, can hide an enormous amount of variability concerning what may be complex responses to climate change. There is enormous heterogeneity in households' access to resources, poverty levels, and ability to cope, and in such circumstances, to talk of average or regional responses borders on the meaningless. Vulnerability and impact assessment work can certainly be usefully guided by macro-level analyses, but ultimately this work really needs to be done at higher resolutions, such as the regional and national levels. This is to acknowledge that there is a considerable tension between the magnitude of the problems facing sub-Saharan Africa, and what can be done to help communities adapt, that fit local conditions. This implies that the conventional wisdom of agricultural research for development as the producer of outputs that are applicable to very large demand domains has to be replaced with another sort of wisdom that acknowledges the heterogeneity and complexity of the world, and accepts that the development domains may be geographically much smaller than previously anticipated, but at the same time the research impacts themselves may be far better targetted. This might be referred to as the spatial resolution issue.

A second key point that these results have highlighted is also an obvious one, but it is the observation that (relatively) local responses to climate change through time are not necessarily linear. This might be termed the temporal resolution issue. In terms of adaptation strategies, more work is needed on the dynamics of change through time and on the dynamics of household responses. Snapshots of conditions now and in 2020 and 2050 are undoubtedly useful, but these snapshots may give a very incomplete picture of the rates and even the direction of change, as these may alter considerably through time. If adaptation itself has to be seen as an essentially dynamic, continuous and non-linear process, this has considerable implications for the tools and methods needed to guide it, and the indicators and threshold analyses that will be part of it.

There are good prospects for being able to address many of the technical issues involved. The fourth assessment report of the IPCC is due to be published in 2007, and the updated summary of the "state of the art" will doubtless suggest many new avenues of research. With improved climate and regional models, better standards for cross-model comparison, and improved techniques for statistical testing, we will be able to rerun the sorts of analysis reported here and in the process generate much more information on model error and hence be in a better position to derive the confidence intervals that are associated with the results of such analysis.

At the same time, there are many organisational changes that are required. Yasmin et al. (2005) see it as crucial that communities start to take centre stage in conducting vulnerability analysis and implementation to enhance their long-term capacities for adaptation. This is echoed in strategy documents from donors such as DFID (2005b) and IDRC (2004), for example. DFID's draft strategy for research on sustainable agriculture for the coming decade is built around three intertwined approaches:

- participation, working with poor farmers to identify and tackle their key problems;
- technology development that can address production issues and enhance resilience to global change; and
- access, developing and implementing systems whereby poor people get access to options and can make choices (DFID, 2005b).

The outlook for Africa under a "business-as-usual" scenario is pretty bleak. On the one hand, Africa appears to have some of the greatest burdens of climate change impacts, certainly from the human health perspective, but it is also a region with generally limited ability to cope and adapt. On the other hand, Africa has some of the lowest per capita emissions of the greenhouse gases that contribute to global warming. The likely impacts of climate change thus present a global ethical challenge as well as a development and scientific challenge (Patz et al., 2005), and this challenge has to be addressed by all of us in all seriousness.

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Acronyms

Acronyms

ACTS	African Centre for Technology Studies
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CGIAR	Consultative Group on International Agricultural Research
DFID	Department for International Development
ENSO	El Niño Southern Oscillation
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FEWS NET	Famine Early Warning System Network
FIVIMS	Food Insecurity and Vulnerability Information and Mapping Systems
GCM	General Circulation Model
GDP	Gross Domestic Product
HadCM3	United Kingdom Meteorological Office Hadley Centre Coupled GCM
IAASTD	International Assessment of Agricultural Science and Technology for Development
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate Prediction
KST	Knowledge, Science and Technology
MDG	Millennium Development Goal
MEA	Millennium Ecosystem Assessment
NEPAD	New Partnership for Africa's Development
PCA	Principal Components Analysis
RCM	Regional Climate Model
RNRRS	Renewable Natural Resources Research Strategy
SADC	Southern African Development Community
SAKSS	Strategic Analysis and Knowledge Support System
SLP	System-wide Livestock Programme
SSA	Sub-Saharan Africa
SSA CP	Sub-Saharan Africa Challenge Programme
SRES	Special Report on Emissions Scenarios
TERI	The Energy & Resources Institute
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

Appendices

Appendix 1. Inception workshop participants
ILRI, Nairobi, 22-23 September 2005

		Name	Institution	Area	Contact
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Appendix 2. Candidate vulnerability indicators identified at the September 2005 workshop

	Variables, Proxies	Components, Data Sources
Natural Capital		
Ecosystem goods & services	1. Surface water	Rivers, lakes, basins
	2. Land-use types	Global land cover, crops, livestock
	3. Biodiversity	Large mammals database
	4. Marine & freshwater fish resources	?
Agro-ecozones	4. LGP, current & future	Data sets at various resolution
	5. Rainfall CV, current & future	Current can be generated, future ?
Land form	6. Agricultural suitability	Terrastat (FAO)
	7. Soil degradation	GLASOD
	8. Land slope	Terrastat (FAO)
Physical/Social Capital		
Infrastructure, asset ownership	9. Access to urban areas (physical)	CIESIN, UNEP, HDI
	10. Access to education & health facilities (social)	
	11. Access to communication, cellphone networks (physical)	
	12. Access to electricity (physical)	
	13. Access to extension (social)	
	14. Access to drinking water (physical)	
Social Capital		
Government response, government capacity, pro-adaptive policies	15. % of GDP spent on social programs (health, education, agriculture & rural development)	HDI
	16. Policy index – types of policies, decentralization	WB
Food security	17. Food security index	Food security maps or CIESIN malnutrition maps
Human Capital		
Population	18. Pop density current	GRUMP or GPW
	19. Growth rate current	GRUMP or FAOSTAT (urban/rural)
Poverty	20. Poverty proxy	HPI, HDI
Migration, urbanization	21. Rate of urbanization	GRUMP, estimate rates by system
Human health	22. Malaria, HIV/AIDS prevalence/risk	Wellcome malaria maps, HDI
Financial Capital		
Agriculture as a % of GDP	23. Agriculture as a % of GDP	WB
Globalization	24. Balance of trade	WB
	25. Foreign direct investment	
Access to credit & financial networks	26. Some accessibility index	HDI

Appendix 3. Country by system CV of annual rainfall (%) – current conditions, simulated using MarkSim (see text for details)

RAIN CV	COAST	FORST	PEREN	LGA	LGH	LGHYP	LGT	MIA	MIH	MIHYP	MRA	MRH	MRHYP	MRT	OTHER	RITRE	TREEC	URBAN
Angola	0.0	18.8	0.0	24.7	19.9	53.2	20.9	0.0	0.0	0.0	24.9	20.1	0.0	19.9	20.8	0.0	20.4	0.0
Benin	32.0	0.0	0.0	29.4	24.8	0.0	0.0	0.0	25.0	0.0	30.4	25.6	0.0	0.0	32.5	0.0	0.0	0.0
Botswana	0.0	0.0	0.0	27.8	0.0	30.0	0.0	0.0	0.0	0.0	27.7	0.0	29.2	0.0	0.0	0.0	0.0	29.0
Burkina Faso	0.0	0.0	0.0	33.6	0.0	0.0	0.0	0.0	0.0	0.0	33.6	0.0	0.0	0.0	32.0	0.0	0.0	0.0
Burundi	0.0	0.0	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.6	0.0	19.9	22.2	0.0	0.0	0.0
Cameroon	14.9	19.2	0.0	28.7	23.9	0.0	23.8	0.0	0.0	0.0	33.1	18.3	0.0	18.6	18.5	0.0	17.3	21.0
Cent Afr Rep	0.0	18.5	0.0	28.3	22.7	0.0	0.0	0.0	0.0	0.0	32.9	19.0	0.0	0.0	25.1	0.0	0.0	0.0
Chad	0.0	0.0	0.0	38.6	0.0	87.9	0.0	42.8	0.0	0.0	35.5	0.0	0.0	0.0	33.8	0.0	0.0	0.0
Congo	17.2	17.8	0.0	0.0	18.3	0.0	0.0	0.0	0.0	0.0	0.0	18.9	0.0	0.0	20.3	0.0	19.3	17.0
DR of Congo	0.0	17.3	19.8	22.5	18.2	23.0	21.4	0.0	0.0	0.0	24.7	17.3	0.0	19.5	20.4	0.0	16.2	20.0
Cote D'Ivoire	18.1	0.0	0.0	26.4	24.4	0.0	0.0	0.0	0.0	0.0	25.6	21.1	0.0	0.0	23.7	0.0	19.0	0.0
Djibouti	0.0	0.0	0.0	0.0	0.0	51.0	0.0	0.0	0.0	0.0	0.0	0.0	57.0	0.0	40.3	0.0	0.0	0.0
Equatorial Guinea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.3	0.0	0.0	0.0
Eritrea	0.0	0.0	0.0	39.8	0.0	44.2	27.7	0.0	0.0	0.0	35.2	0.0	35.0	33.1	0.0	0.0	0.0	0.0
Ethiopia	0.0	0.0	18.3	32.1	23.5	40.3	29.1	0.0	0.0	0.0	27.7	21.9	34.5	23.6	49.0	0.0	0.0	0.0
Gabon	17.7	16.5	0.0	0.0	17.8	0.0	0.0	0.0	0.0	0.0	0.0	16.1	0.0	0.0	16.0	0.0	15.8	0.0
Gambia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	0.0	0.0	37.0	0.0	0.0	0.0
Ghana	16.0	0.0	0.0	26.9	24.6	0.0	0.0	0.0	0.0	0.0	27.4	21.2	0.0	0.0	20.7	0.0	20.5	22.6
Guinea Bissau	40.0	0.0	0.0	33.6	0.0	0.0	0.0	36.0	0.0	0.0	33.8	0.0	0.0	0.0	29.6	0.0	0.0	0.0
Guinea	22.0	0.0	0.0	29.9	24.3	0.0	0.0	29.0	0.0	0.0	28.6	22.6	0.0	0.0	21.9	0.0	18.0	0.0
Kenya	26.1	0.0	22.8	29.9	0.0	36.6	23.9	0.0	0.0	0.0	25.3	19.7	29.6	21.5	27.2	0.0	29.0	25.0
Lesotho	0.0	0.0	0.0	0.0	0.0	0.0	22.8	0.0	0.0	0.0	0.0	0.0	0.0	21.8	0.0	0.0	0.0	0.0
LIberia	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.1	0.0	0.0	15.5	0.0	15.0	0.0
Madagascar	20.3	18.4	0.0	21.4	16.3	26.6	19.4	0.0	0.0	0.0	20.0	16.2	26.0	19.7	23.1	17.7	0.0	0.0

Malawi	0.0	0.0	0.0	23.6	22.4	0.0	24.3	0.0	0.0	0.0	24.4	21.0	0.0	24.8	22.7	0.0	0.0	26.0
Mali	0.0	0.0	0.0	38.6	0.0	72.3	0.0	42.6	0.0	0.0	36.6	0.0	52.3	0.0	45.5	0.0	0.0	0.0
Mauritania	0.0	0.0	0.0	44.2	0.0	76.6	0.0	50.0	0.0	51.0	42.9	0.0	49.0	0.0	56.0	0.0	0.0	0.0
Mozambique	21.0	0.0	0.0	23.4	17.3	27.4	27.0	0.0	0.0	0.0	23.4	18.0	28.0	0.0	22.4	0.0	0.0	0.0
Namibia	0.0	0.0	0.0	27.6	0.0	47.7	41.0	0.0	0.0	0.0	27.3	0.0	35.5	0.0	0.0	0.0	0.0	0.0
Niger	0.0	0.0	0.0	43.2	0.0	82.2	0.0	49.5	0.0	0.0	37.4	0.0	0.0	0.0	40.5	0.0	0.0	0.0
Nigeria	15.1	0.0	0.0	36.1	25.4	0.0	28.0	35.7	26.0	0.0	33.5	22.4	0.0	26.2	25.8	0.0	17.6	21.8
Rwanda	0.0	0.0	19.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.7	19.5	0.0	19.7	0.0	0.0	0.0	0.0
Senegal	40.0	0.0	0.0	39.0	0.0	55.3	0.0	40.3	0.0	52.0	40.2	0.0	54.0	0.0	44.7	0.0	0.0	0.0
Sierra Leone	16.5	0.0	0.0	0.0	19.4	0.0	0.0	0.0	0.0	0.0	0.0	17.1	0.0	0.0	19.4	0.0	14.4	0.0
Somalia	0.0	0.0	0.0	34.4	0.0	47.4	42.0	33.7	0.0	0.0	36.9	0.0	34.0	0.0	42.0	0.0	0.0	0.0
South Africa	0.0	0.0	0.0	24.1	20.5	35.2	22.9	0.0	0.0	29.3	23.8	20.3	26.9	22.9	23.1	0.0	0.0	23.2
Sudan	0.0	0.0	0.0	36.2	24.8	79.9	24.3	44.9	0.0	51.4	34.7	21.7	32.5	30.0	31.4	0.0	0.0	48.5
Swaziland	0.0	0.0	0.0	23.7	0.0	24.0	0.0	0.0	0.0	0.0	23.0	0.0	24.5	21.5	23.0	0.0	0.0	0.0
Tanzania	20.8	0.0	19.3	23.9	21.7	23.3	23.7	0.0	0.0	0.0	24.3	20.8	27.0	23.3	21.6	0.0	23.1	22.0
Togo	0.0	0.0	0.0	25.8	0.0	0.0	0.0	0.0	0.0	0.0	27.0	21.7	0.0	0.0	22.0	0.0	18.0	0.0
Uganda	0.0	0.0	21.2	25.6	21.7	28.0	23.5	0.0	0.0	0.0	24.0	21.5	29.0	22.1	19.0	0.0	0.0	0.0
Zambia	0.0	0.0	0.0	24.2	21.0	0.0	24.9	0.0	0.0	0.0	24.9	23.0	0.0	24.6	23.1	0.0	0.0	28.0
Zimbabwe	0.0	0.0	0.0	25.9	0.0	28.8	24.6	0.0	0.0	0.0	26.0	0.0	28.7	23.7	22.7	0.0	0.0	26.7

Appendix 4

List of contacted institutions for the information survey

Name Of Institution	Country	Region	Response
Environmental Development Action in the third world (ENDA)	Senegal	West Africa	Responded
Zimbabwe Regional Environmental Organization (ZERO)	Zimbabwe	Southern Africa	Responded
Sudanese Environment Conservation Society (SECS)	Sudan	East Africa	No response
Environmental Protection and Management Services (EPMS)	Tanzania	East Africa	No response
Development Network for Indigenous Voluntary Association (DENIVA)	Uganda	East Africa	Responded
TENMIYA	Mauritania	West Africa	No response
AMADE PELCODE	Mali	West Africa	Responded
Organisation des Femmes pour la Gestion de l'Energie, de l'Environnement et la promotion du Développement Intégré (OFEDI)	Benin	West Africa	No response
Coordination Unit for the Rehabilitation of the Environment (CURE)	Malawi	Southern Africa	Responded
Action Group for Renewable energies and Sustainable Development (GED)	Mozambique	Southern Africa	Responded
Energy and Environmental Concerns for Zambia (EECZ)	Zambia	Southern Africa	No response
South South North Group (SSN)	South Africa	Southern Africa	Responded
Action Aid International	Kenya	East Africa	Responded
Ministry of Heath	Kenya	East Africa	Responded
Ministry of Planning & National Development	Kenya	East Africa	Responded
Maseno University	Kenya	East Africa	Responded
Sahelian Solutions (SASOL)	Kenya	East Africa	Responded
BEA International	Kenya	East Africa	Responded
Kenya Forestry Research Institute(KEFRI)	Kenya	East Africa	Responded

Climate Network Africa (CAN)	Kenya	East Africa	Responded
National Association of Professional Environmentalist (NAPE)	Uganda	East Africa	Responded
Higher Council for Environment and Natural Resource	Sudan	Horn of Africa	Responded
Environmental Protection Agency	Ghana	West Africa	Responded
Department of Meteorological Services	Botswana	Southern Africa	Responded
Arid Lands Management Project	Kenya	East Africa	No response
FEWSNET	Kenya	East Africa	No response
Environmental Affairs Department	Malawi	Southern Africa	No response
Ministry of Natural Resources	Lesotho	Southern Africa	No response
Meteorological Services	Malawi	Southern Africa	No response
Environmental Council of Zambia	Zambia	Southern Africa	No response
Lesotho Meteorological Services	Lesotho	Southern Africa	No response
Ministry of Tourism, Environment and Natural Resources, Zambia	Zambia	Southern Africa	No response
Division of Environment	Tanzania	East Africa	No response
Kenya Meteorological Department	Kenya	East Africa	Responded
ICPAC formerly Drought Monitoring Centre	Kenya	East Africa	Responded

Questionnaires were sent to 35 institutions in the region out of which 21 responded.

Note 1

Indicators of Adaptive Capacity

Note 1. Indicators of Adaptive Capacity

(prepared by Ms Suruchi Bhadwal, TERI)

Adaptive capacity: concepts and frameworks

The science on dealing with the 'impacts, vulnerability and adaptation' to climate change has overseen many developments over time. The developments are mostly with regard to the various concepts and frameworks that have been introduced and discussed in context. While the focus was initially on impacts assessments, there has been a gradual shift towards vulnerability assessments and assessment of adaptive capacities, placing adaptation in context. Adaptation depends greatly on the adaptive capacity or adaptability of an affected system, region or community to be able to cope effectively with the impacts and risks of climate change (IPCC, 2001).

While the IPCC first assessment report presented a broader framework, the Second Assessment Report mentioned that the vulnerability of a system increases as adaptive capacity decreases, highlighting an inverse relationship with each other. It had defined that factors that help in determining successful adaptation include technological advances, institutional arrangements, availability of financing and information exchange. The Third Assessment report further to this defined vulnerability to climate change as a measure of 'the extent to which regions are likely to be influenced by climate change, given the inherent adaptive capacities that exist in those regions in being able to respond effectively to the expected changes'. It is thus concluded that vulnerability of a given system (natural or human) largely depends on the adaptive capacities of the system and its potential in coping effectively with the impacts and the risks so associated:

$$V = f_x (I - AC)$$

where V = Vulnerability, I = Impacts, AC = Adaptive Capacity

Given the above equation, vulnerability is defined as a function of a range of biophysical and socioeconomic factors, commonly aggregated into three components that includes an estimate of adaptive capacity, sensitivity, and exposure to climate variability and change (see Box 1 below for definitions on each). While sensitivity and exposure to current climate variability and climate change provide an estimate of the likely impacts across regions, socioeconomic factors play an important role in determining the extent of vulnerability in those regions, given the underlying adaptive capacities that prevail in those regions.

Box 1: Source: IPCC, 2001

1. Adaptive capacity describes the ability of a system to adjust to actual or expected climate stresses, or to cope with the consequences

2. Sensitivity refers to the degree to which a system will respond to a change in climate, either positively or negatively.

3. Exposure relates to the degree of climate stress upon a particular unit of analysis; it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events.

Adaptive capacity is therefore defined as "the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change" (Smit and Pilifosova, 2001). In the case of communities it is determined by the socioeconomic characteristics of the communities and their abilities in responding effectively. The capacity to adapt varies across regions, countries, and socioeconomic groups and will vary over time. The most vulnerable regions and communities are those that are highly exposed to the changes expected in the climate and have limited adaptive capacity. Countries with limited economic resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions, and inequitable empowerment and access to resources have little capacity to adapt and are highly vulnerable (IPCC, 2001). Therefore, enhancement of adaptive capacity is a necessary condition to reduce vulnerability, particularly for the most vulnerable regions, nations or socioeconomic groups.

Enhancement of adaptive capacity presents a practical way of coping with changes and uncertainties in climate, including variability and extremes, reducing vulnerability and promoting sustainable development.

According to Bohle et al (1994), adaptive capacity is based on diverse system endowments, including technology, knowledge, wealth, and socio-ecological attributes. The IPCC Working Group II, Third Assessment Report defines adaptive capacity categorically as a function of certain key factors taking into account indicators of "wealth, technology, education, information, skills, infrastructure, access to resources, and stability and management capabilities" (IPCC, 2001). Broadly, this is understood as constituted by economic, social, technological, and biophysical factors as defined by Chambers (1989) and Bohle et al. (1994). Yohe and Tol (2002) define the determinants of adaptive capacity as the range of available technological options for adaptation, availability of resources and their distribution across the population, structure of critical institutions and decision-making, human capital, including education and personal security, social capital, including property rights, a system's access to risk-spreading processes, ability of decision-makers to manage information, and the public's perceived attribution of the source of stress. Smit et al. (2001) have drawn a framework to define the key determinants of adaptive capacity, summarized in Table 1.

Table 1. Determinants of adaptive capacity

Determinant	Explanation
Economic resources	▪ Greater economic resources increase adaptive capacity ▪ Lack of financial resources limits adaptation options
Technology	▪ Lack of technology limits range of potential adaptation options ▪ Less technologically advanced regions are less likely to develop and/or implement technological adaptations
Information and skills	▪ Lack of informed, skilled and trained personnel reduces adaptive capacity ▪ Greater access to information increases likelihood of timely and appropriate adaptation
Infrastructure	▪ Greater variety of infrastructure can enhance adaptive capacity, since it provides more options ▪ Characteristics and location of infrastructure also affect adaptive capacity
Institutions	▪ Well-developed social institutions help to reduce impacts of climate-related risks, and therefore increase adaptive capacity ▪ Policies and regulations have constrain or enhance adaptive capacity
Equity	▪ Equitable distribution of resources increases adaptive capacity ▪ Both availability of, and entitlement to, resources is important

Arguments by O'Brien et al. (2004a) indicate that the adaptive capacity approach leads to the emergence of policy measures that focus less on technical aspects and more on social aspects, including poverty reduction, diversification of livelihoods, protection of common property resources, and strengthening of collective action. Such measures enhance the ability to respond to stressors and secure livelihoods under present stress, which can also reduce vulnerability to future climate conditions. One way of operationalising this is by first understanding the distribution of vulnerability and identification of "hotspots" through vulnerability mapping. At a more local scale, case studies can provide insights into the underlying causes and structures that shape vulnerability (O'Brien et al., 2004b), given the inherent capacities that exist across regions to adapt.

Mapping adaptive capacity and vulnerability: TERI case study

The TERI case study has attempted to map adaptive capacity at a sub-national level using the agricultural sector of India as an illustration. Along with other institutions like CICERO, IISD and Rutgers University, a method for mapping adaptive capacity and vulnerability at the sub-national level has been suggested. Though used in the context of the agricultural sector, this method is replicable and can be used to assess differential vulnerability for any particular sector within a nation or region. "Adaptive capacity" in the context of the study was defined as a measure of certain "identified" biophysical, socioeconomic, and technological factors. Indicators were identified based on its local relevance and importance in the context of the sector being dealt with.

The biophysical indicators used in the profile consisted of soil conditions (quality and depth) and ground water availability. Socioeconomic factors consisted of levels of human and social capital, and the presence or lack of alternative economic activities. The former was represented by literacy rates and gender equity, and the latter by the percentage of farmers and agricultural wage labourers in a district. Technological factors consisted of the availability of irrigation and quality of infrastructure. The indices representing biophysical, social, and technological vulnerability were averaged (i.e., equally weighted) to produce a final index of adaptive capacity. The data sources include published information and data from several sources including publications of the Government of India. A series of maps has been constructed using a GIS, with district (lowest administrative unit within the country) as a spatial unit of analysis. For each component of vulnerability, a number of indicators were compiled, normalized, scaled, weighted, and mapped (TERI, 2003).

TERI study and construction of index of adaptive capacity

The indices in the vulnerability profiles are constructed based on the method used in UNDP's Human Development Index (UNDP, 2002). The values of each indicator are normalized to the range of values in the data set, by applying the following general formula:

$$\text{Index value} = \frac{(\text{actual value} - \text{minimum value}) * 100}{(\text{Maximum value} - \text{minimum value})}$$

In some cases, the index values by using [100 – index value] were reversed. This reversal is necessary to ensure that high index values indicate high vulnerability in all cases. In the case of literacy rates, for example, where a higher literacy level indicates higher degrees of human capital and lower levels of vulnerability, the index value is reversed, so that a high index value corresponds to low levels of literacy (i.e., high vulnerability). Each indicator was evaluated in this manner, prior to construction of the composite indices.

As mentioned above, adaptive capacity is understood as being constituted by three broad sets of factors: social, technological, and biophysical (Chambers, 1989; Bohle et al., 1994). A composite index for each these factors was constructed based on data from 1991. These include a social vulnerability index, a technological vulnerability index, and a biophysical vulnerability index. The final index of adaptive capacity for each district is calculated as the average of these three indices.

1. Social Vulnerability Index

Dimension	*Indicator*	*Dimension Index*	
Agricultural dependency	Percentage of district workers employed in agriculture	Agricultural Dependency Index	**Social Vulnerability Index**
Vulnerability of agricultural workforce	Percentage of landless labourers in agricultural workforce	Landlessness Index	
Human capital	Adult literacy rate (>7 years)	Education Index [100 – index value]	
Female disadvantage	"Missing girls" i.e., less than 48.5% girls in 0-6 population	Female Disadvantage Index [100-index value]	
Female literacy and child survival chances	Female literacy rate	Female Literacy and Child Survival Index [100 – index value]	

Agricultural dependency is measured by the percentage of the district workforce employed in agriculture. A high level of agricultural dependency will increase the district's vulnerability to climate variability and fluctuations in agricultural terms of trade.

Vulnerability of agricultural workforce, as measured by the percentage of landless labourers in the agricultural workforce, provides an indication of inequality in landholdings. Landless labourers are generally poor and have little security of income: in times of agricultural distress, labourers are the first to lose their income. A district with a larger share of landless labourers in the agricultural workforce is thus more vulnerable to social and economic disruption as the result of drought or other climatic stress.

Human capital is measured by the literacy level in the adult population (>7 years). Increased overall literacy levels reduce vulnerability by increasing people's capabilities and access to information and thus their ability to cope with adversities.

Gender discrimination is measured by excess girl child mortality ("missing girls"). The index measures the deviance from a normal demographic sex composition in the 0-7 year population. The demographic, natural normal composition would be 48.7% girls and 51.3% boys. A girl percent of 48.5 and below is due to unnatural causes, like sex-specific abortions and excess mortality. The indicator thus ranks all districts from the lowest percent of girls to 48.5% girls, saying that 48.5% and above is not vulnerable, but below that vulnerability for women is increasing linearly to the lowest percentage.

Female literacy and child survival chances are measured by female literacy rate. Empirical studies have shown that increased female literacy has a significant impact on child mortality rates and fertility rates. Cross-sectional analyses of district level data in India have shown that the male literacy rate is only significantly associated with the reduction of male child mortality, thus increasing female disadvantage relative to boys. Female literacy has a negative and statistically significant effect on the mortality of both boys and girls, and "reduces child mortality and anti-female bias in child survival independently of male literacy" (Murthi et al., 1995). Although infant mortality rates would be a more direct indicator of child survival chances, these data are not available at the district level. Consistent data on poverty rates are also not available at the district level, but studies show that "female literacy rate is a much better 'predictor' of child mortality in different states than per-capita expenditure" (Drèze and Sen, 2002).

2. Technological Vulnerability Index

Dimension	*Indicator*	*Dimension Index*	
Vulnerability to rainfall variability	Irrigation rate	Irrigation Index	**Technological Vulnerability Index**
Infrastructure development	Composite index of infrastructure development	Infrastructure Development Index	

The Technological Vulnerability Index illustrates the relative technological vulnerability of a district by using indicators that measure a district's technological capacity or access to technology.

Irrigation rate is measured by net irrigated area as percentage of net sown area. Water scarcity is the main productivity constraint for Indian agriculture. Our case studies show that assured irrigation reduces farmers' vulnerability to low and erratic rainfall. Irrigation data was available for most of the districts of India in 1991 from the Agricultural Census. However, a total of 63 districts (many in the northeast) were missing irrigation data in the Agricultural Census.

Quality of infrastructure is an important measure of relative adaptive capacity of a district, and districts with better infrastructure are presumed to be better able to adapt to climatic stresses.

3. Biophysical vulnerability Index

Dimension	*Indicator*	*Dimension Index*	
Soil quality	Depth of soil cover	Soil quality index	**Biophysical Vulnerability Index**
	Soil degradation severity		
Groundwater availability	Replenishable groundwater available for future use, in million cubic meters	Groundwater Scarcity Index	

We assume that areas with more productive soil and more groundwater available for agriculture will be more adaptable to adverse climatic conditions and better able to compete and utilize the opportunities of trade.

Indicators for soil quality are the depth of the soil cover in cm and severity of soil degradation. Data source for depth of soil cover was digitized from a soil cover map of India from the Atlas of Agricultural Resources of India (NATMO, 1980). The map is on a scale of 1:6 million and classifies the soil depth into five categories: 0-25 cm, 25-30 cm, 50-100 cm, 100-300 cm, and more than 300 cm. The categories were rescaled from 1 to 100 (to conform to the normalization procedure) where Class 1 = 100 (or highest vulnerability/ shallowest soil depth), Class 2 = 75, Class 3 = 50, Class 4 = 25 and Class 5 = 0 (or least vulnerable/ thickest soil cover). The soil cover map was converted to a grid with a cell size of 5.33 km. By converting the polygon data to grid level it was possible to create fuzzy boundaries between soil cover classes and interpolate new cell values for areas on the borders of polygons. The gridded data was then averaged up to district (polygon) level where each district was given an average soil cover value.

Data for the severity of soil degradation was digitized from the "India Soil Degradation - Human Induced" map (scale 1:4.4 million) of the National Bureau of Soil Survey and Land Use Planning (NBSS-LUP, 1994). This composite map is based on three indices: 1) types of soil degradation; 2) degree of degradation; and 3) extent of degradation. Types of degradation include water erosion, wind erosion, chemical deterioration (salinization, loss of nutrients), physical deterioration (water logging), stable terrain (with slight water erosion) and soil not fit for agriculture. The table below gives details/sub-classes of soil degradation considered for development of the composite map. The degree of degradation is measured in terms of reduced agricultural productivity and is classified as follows:
1) Slight (somewhat reduced agricultural productivity);
2) Moderate (greatly reduced agricultural productivity);
3) Strong (unreclaimable at farm level); and
4) Extreme (unreclaimable and impossible to restore).

Extent of degradation takes into account the area affected (classified into five categories: 5%, 10%, 25%, 50% and 100%). Based on degree of degradation and percentage of area affected, different levels of severity of degradation were obtained (low, medium, high and very high). Soil degradation was then reclassified to range between 0 and 100 where Low = 0, Medium = 33, High = 66, and Very High = 100. The same procedure followed for soil cover was used to convert the polygon data to a grid, and then back to district-level polygons.

Data on replenishable ground water resources is taken from Central Ground Water Board, Ministry of Water Resources (Groundwater Statistics, 1996). It is calculated as the total amount of groundwater which is replenishable annually, measured in million cubic meters/year (MCM/Yr). This depends on the amount of rainfall, recharge from the canals, surface water bodies and change in land cover.

4. Validation of the Index

Some literature on index construction argues that a good measure of the validity of the index is the internal correlation between the individual indicators used in the index (Carmines and Zeller, 1977; Bohrnstedt and Knoke, 1994; Bryman and Cramer, 1997). The relevance of this criterion will, however, depend on the relationship between the indicators and the construct they are intended to measure. This depends on whether the index is based on a "reflexive" or a "formative" measurement model. In a reflexive model, the index is a measure of an underlying construct which is thought to influence the indicators. In a formative measurement model, the index is measuring a phenomenon or construct which is influenced by the indicators (Hellevik, 2002). In this case the index is an example of the latter; as the indicators are assumed to be contributing to vulnerability, not the other way around. Different properties and factors will contribute to the vulnerability of area region or an individual, for instance soil degradation, literacy rates and irrigation rates, but these need not necessarily correlate with each other. If all vulnerability-increasing properties are present, we assume that vulnerability is increased and compounded. A poverty index, on the other hand, is most often an example of a reflexive model, whereby the construct, poverty, is thought to influence the various indicators chosen, such as literacy, expenditure, housing standard and ownership of assets. Our aim was to construct an index that captures a number of different dimensions that influence vulnerability.

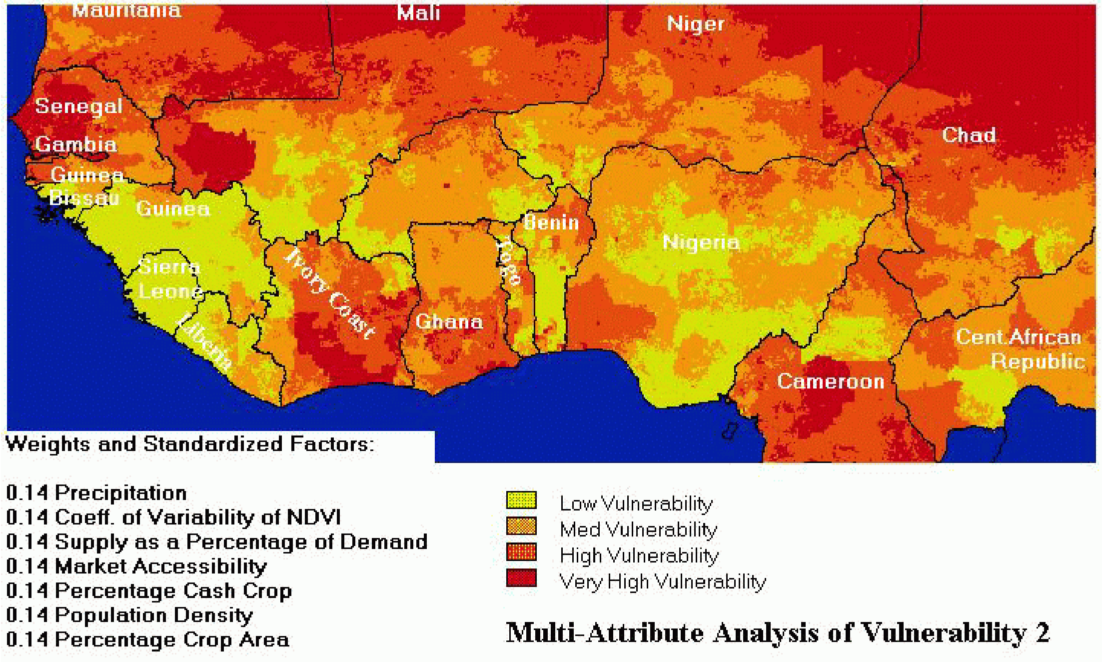
Placing Africa in context

Understanding the regional and local dimensions of vulnerability is essential to develop appropriate and targeted adaptation efforts. Responding to climate variability is of immediate concern to Africa, given its variable climate and reliance on natural resources in economic activities. Adaptive capacity of human systems in Africa is low due to lack of economic resources and technology, and vulnerability high as a result of heavy reliance on rain-fed agriculture, frequent droughts and floods, and poverty. Grain yields are projected to decrease for many scenarios, diminishing food security, particularly in small food-importing countries. Major rivers of Africa are highly sensitive to climate variation; average runoff and water availability would decrease in Mediterranean and southern countries of Africa. Extension of ranges of infectious disease vectors would adversely affect human health in Africa. Desertification would be exacerbated by reductions in average annual rainfall, runoff, and soil moisture, especially in southern, North, and West Africa. Increases in droughts, floods, and other extreme events would add to stresses on water resources, food security, human health, and infrastructures, and would constrain development in Africa. Significant extinctions of plant and animal species are projected and would impact rural livelihoods, tourism, and genetic resources. Coastal settlements in, for example, the Gulf of Guinea, Senegal, Gambia, Egypt, and along the East-Southern African coast would be adversely impacted by sea-level rise through inundation and coastal erosion (IPCC, 2001).

Some studies have carried out vulnerability assessments for Africa and a sample of proposed variables for characterizing dynamic vulnerability is listed below (adapted from Ramachandran and Eastman,1997).

Traditional Indicators of Vulnerability
Share of drought resistance crops Agroclimatic Zones Average NDVI for last three seasons Rainfall index Frequency of drought by watershed Percentage crop area Variability of agricultural production Access to infrastructure Average cash income Population density Infant mortality index Female literacy rate Average cost to travel to district market Civil insecurity
Indicators of Dynamic Vulnerability
Change of access or levels of investment in transportation and other infrastructure Change in availability of marketing facilities Change in access to credit Change in crop subsidy prices Change in national trade or investment policy Change in national or regional industrial structure Change in soil fertility Change in climate Large scale international movement of people Changes in rates of HIV/AIDS among households Escalation of civil war or other military conflict

Based on the selected variables a dynamic vulnerability profile was developed for Western Africa highlighting regions of high and low vulnerability (see Figure 1 below).



Similarly, Adger and others present a Social Vulnerability Index (SVI) for African Nation States aiming to address the uncertainties associated with the assessment of adaptive capacities. The SVI is an aggregate index of human vulnerability to climate change induced change sin water availability formed from a weighted average of five composite sub-indices: economic well-being and stability, demographic structure, institutional stability and strength of public infrastructure, global interconnectivity and dependence on natural resources. Thee ranking basically highlighting countries such as Niger, Sierra Lone, Burundi, Madagascar, Burkina Faso, Uganda, Ethiopia, Mauritania, Lesotho, Tanzania, Cameroon, Togo and Rwanda as the worst affected and with least capacities. While there have been few studies that have assessed vulnerability and associated adaptive capacities in Africa, these studies have been carried out in pocketed ways. The study here, however, aims to cover all countries within Africa to capture the varying adaptive capacities and vulnerabilities enabling identification of countries where detailed assessments and interventions are required.

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Yohe and Tol 2002

Note 2

South-South Cooperation

Note 2. South-South Cooperation

(prepared by Ms Sreeja Nair and Dr Vivek Kumar, TERI)

Genesis of the concept of south-south cooperation

The notion of international cooperation came to existence with the UN charter, which pledges to "employ international machinery for the promotion of the economic and social development of all people". For a long time the international cooperation was considered between the industrialized world and the developing world because of the obvious fact that the industrialized world was economically well off and had access to advanced technologies and practices which could be shared with the developing countries for their development.

The 'north-south cooperation' and technology transfer from the north to south was considered as the bridge to fill the technological competence gulf between the developed and the developing countries. For instance, the Vienna Convention (1979) on Science and Technology (S&T) for Development undertook to establish funds for S&T projects in developing nations. This was followed by international agreements with provisions for technology transfer, among which the prominent ones are the UN Conventions on Biodiversity, Climate Change and Combating Desertification. In 2005, the UN Commission on S&T for Development hinted on the responsibility of the developed countries to transfer technology to the South.

Over the years it was realized that within the group of developing countries also there were marked differences. This made people to think of cooperation among the developing countries themselves thus giving rise to the concept of 'south-south cooperation' (SSC). The use of the term 'south' has often been used in the realm of international interaction to entail the fact that all the developed nations of the world (barring Australia and New Zealand) lie to the north of the developing nations.

Need for SSC: shared goals and challenges of the South

The countries in the south generally share certain commonalities such as similar developmental experience and are also faced with common challenges such as high population pressure, poverty, hunger, disease, environmental deterioration, etc. In view of this, south-south cooperation is clearly becoming more relevant.

Further, the technology is often limited in terms of its applicability to specific ecosystem dynamics. For example, the technology applicable in the temperate zone is different from that required in the tropics and also the market scenario in response to the demand in the tropics is different from the one that exists in the developed countries.

South-south cooperation: more promising and appropriate?

In addition to the above factors, several geopolitical developments emphasise the need for south-south cooperation. Some of these factors may be:

- The focus of research activities in the industrialized countries is gradually moving from the public to private sector. The private sector aims at maintaining their technological edge over the developing countries, and hence are averse to sharing their technology. This is an impediment for the scope of potential international research collaborations with developing countries, which depend highly on the public sector.

- The interest of many developed countries in helping developing countries seems to be receding, e.g. the monetary support for the flagship Consultative Group on International Agricultural Research (for promotion of sustainable agricultural development) has been diminishing.

- On the other hand, south-south trade has been rising at 11% annually for the past decade. For example, Africa's trade with Asia has risen from about $ 6 billion to around $ 18 billion in the past decade. Also the average annual growth rate in exports of goods and services was higher in developing than developed countries between 1980 and 2002. This gives an insight to the thought that SSC has been delivering visible beneficial results on the economic front (UN, 2004).

- The LDCs (Least Developed Countries) could find economic and sustainable solutions to address their needs and problems, by sharing and learning from the experiences of other developing country counterparts.

- SSC can also boast of being based on abundant networks (social, natural, institutional etc) that support globalisation. Key players in this arena of networking in the South are the East African Community, the African Union, the Caribbean Community, and SAARC (UN, 2004).

Emerging trends for SSC

The arena of SSC has come to address a wide range of issues based on the areas of concerns in the developing countries. For example, owing to the vulnerabilities of the South to natural disasters and combining their inherent lack of adequate coping mechanisms, the need for concerted action on this front has increasingly been felt.

Another trend gaining impetus is decentralized SSC, with cooperative action on an issue, involving human resource outside the Government sphere, such as those from local communities, elected bodies, NGOs, etc. (Juma et al., 2005).

Role of the UN

The UN has continually been supporting various activities to promote SSC in the form of policy support and capacity-building activities among others. UN agencies such as FAO, UNCTAD, ITC, UNIDO and WHO have marked out proper South-South policies and activities.

Drivers of SSC

The developing countries can boast of several factors that can have long lasting benefits in the sphere of development. These factors are:

- Education: The developing nations have nurtured human resource and refined it through their mode of education into a growing asset.
- Effective policy frameworks in countries that have efficient governance and economic set up could share their experiences with other developing countries facing stumbling blocks in their development.
- S&T: Developing countries are rapidly moving ahead towards the creation of knowledge hubs in the form of human resource and opening up avenues for SSC for exchange of technology.

- Institutional capacity: The developing nations are quite proficient in world-class capacities active at the state, society and private sector, owing to immense experience; numerous institutional capacities have been tried and tested.
- Interdependence networks: The South realizes that interdependence between the individuals and the communities can go a long way in overcoming their development challenges.
- Outlook towards globalisation: Many developing countries have been able to derive benefits of globalisation. SSC provides a platform for exchange of experiences and creation of developmental strategies and innovations.
- Support of the North: Shared goals (such as human development, security, peace etc.) can be achieved effectively if SSC can be supplemented by cooperation from the North (UN, 2004).

SSC milestones

The Bandung conference in 1955 was the pioneering major South-South conference of developing countries that paved way for the rise of the Non-Aligned Movement (NAM) and the Group of 77 (Doha, 2005). The Group of 77, created in 1964 (constituting all developing countries in the UN) has always vocalized the issue of cooperation among developing countries. The UNDP was formed in 1965. Presently the UNDP has a major focus on activities in many areas within a global cooperation framework that builds the capacity of developing countries to derive maximum benefits from their traditional knowledge system to address developmental challenges.

The Association of Southeast Asian Nations (ASEAN) was constituted in 1967 and was a stepping-stone towards bringing nations into a framework of cooperation. The expression 'South-South Cooperation' gained impetus owing to efforts by developing nations in the 1970s to begin negotiations in a bid to bridge the economic gap between developed and developing countries.

A Working Group on Technical Cooperation among Developing Countries (TCDC) was created in 1972 by the General Assembly. The main target of the Group was to engage the developing countries proactively in order to achieve key Millennium Development Goals. Recently, a new variety of rice (NERICA- New Rice for Africa) suited to African conditions has been developed with support from Japan. The conference on TCDC held in Buenos Aires in 1978 recommended that for developing countries to realize their potential, they should pave the way for building competence and capacity to strengthen their resource base, and make proper use of opportunities for collaboration with other developing countries.

History of G77- highlights of decisions

- Caracas (1981)- negotiations urged among developing countries, with joint initiatives in marketing and technology transfers
- Cairo (1986)- introduced the notion of sector wise prioritisation, participation of non governmental bodies and highlighted the linkages between peace, security, development and economic cooperation among developing countries
- San Jose (1997)- stressed on strengthening collaborations between public and private sectors, NGOs, community based organizations and civil society. The meeting also focused on agreements in the transport sector to benefit the landlocked and SIDS along with efforts to enhance institutional capacities to adjust to the changes of globalisation
- Bali (1999)- urged creation of consultative mechanisms to encourage study of economic crises on certain developing country groups, provision of professional training for better negotiation skills, and creation of inter regional web from different arena (commerce, industry, scientific community etc.)
- South Summit (2000)- upgraded financial support for the Group, urged coordination of the web of research institutions, publication of annual report on South- South cooperation, development of 'vulnerability index' of the developing nations owing to globalization
- Tehran (2001)- attempted to focus on bridging the gap between the aims and achievements of the Group
- Dubai (2002)- urged establishment of a research network within the South developing countries and study on the necessary funding requirements

Source: UN, 2004

SAARC (South Asian Association for Regional Cooperation) with Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka was formed in 1985, which gradually expanded its crisp focus into greater depths of environmental, social and security sectors. Five SAARC regional centres focus on agricultural information (Bangladesh), tuberculosis prevention (Nepal), meteorological research (Bangladesh), documentation (India) and human resource development (Pakistan) (UNDP, 2004).

As many of the most vulnerable groups and communities within the LDCs will be differentially affected by climate change, the Capacity Strengthening of Least Developed Countries (LDCs) for Adaptation to Climate Change (CLACC) project was initiated by IIED and the RING Partner institutions to enhance the capacity of civil society based organizations working with the poor and vulnerable countries in selected LDCs.

Some initiatives aimed at South –South Cooperation

Many projects are coming into the forefront that place special focus on the development and vulnerability issues in developing countries. One of the many such initiatives has been Assessments of Impacts and Adaptations to Climate Change (AIACC) developed in collaboration with the UNEP/WMO, IPCC and funded by the GEF to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries. By funding collaborative research, training and technical support, AIACC aims to enhance the scientific capacity of developing countries to assess climate change vulnerabilities and adaptations, and generate and communicate information useful for adaptation planning and action. Substantial in-kind support has been donated by participating institutions in developing countries.

Another effort to help communities, policy-makers, practitioners and academicians share knowledge on climate change adaptation is the Linking Climate Adaptation (LCA) Network, funded by DFID. The first phase of the project (May 2004 – June 2005) identified the role of funding and policy mechanisms in order to support successful community-led adaptation. It also identified longer-term research priorities needed to support community led adaptation in the future. As part of the activities of the second phase of the project (November 2005 – March 2006), first, the LCA Network website is being redeveloped as a valuable resource, with ideas for research. Second, structured discussions are being held between LCA Network members exploring the value of NAPAs; the next steps for climate policy and the links between the climate change and disaster communities. Third, efforts will be made to expand and diversify the membership of the LCA Network to create more dynamic exchanges. Finally, IDS (Institute for Development Studies) are organising a meeting in Kenya in March 2006, which will seek to develop synergies between adaptation research and researchers in Africa and Asia in order to fortify the voice of vulnerable countries.

The Capacity Strengthening of Least Developed Countries (LDCs) for Adaptation to Climate Change (CLACC) project initiated by IIED and the RING Partner institutions aims at ameliorating the capacity of civil society based organizations working with the poor and vulnerable countries in 12 selected LDCs (9 in Africa and 3 in South Asia). The CLACC Project started with strengthening capacity of 4 Regional CLACC Partners in South Asia (BCAS) East Africa (ACTS), West Africa (ENDA) and Southern Africa (ZERO) in its first phase during 2004/2005 (CLACC, 2005).

Another such initiative is the New Partnership for Africa's Development (NePAD), an African-led strategy for sustainable development and poverty reduction in Africa. African leaders are looking for support from the international community to achieve these goals. NePAD is a long-term agenda for Africa adopted as a programme of the Africa Union. The NePAD Secretariat is developing an implementation plan and building linkages with existing regional organisations such as the Economic Community of West African States (ECOWAS) and Southern African Development Community (SADC). The Secretariat has engaged with other African

organisations, such as the UN Economic Commission for Africa (ECA) and the Africa Development Bank (AfDB), to elaborate proposals in support of NePAD priorities.
There is also immense scope for technological innovations. For example, early warning and improved information systems can reduce vulnerabilities to climate variability. The southern African countries have established the Southern African Regional Climate Outlook Forum (SARCOF), which is a regional seasonal weather outlook prediction and application process adopted by the 14 countries comprising the Southern African Development Community (SADC) member states: Angola, Botswana, Democratic Republic of Congo, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe along with other partners.

Ways forward

The pivotal role that SSC could play in the arena of development comes from the fact that the developing countries account for a major proportion of the people in the world and some of them are large economies, which have a major share of the world GNP. As the South unites into a single mass, they can voice their opinions and concerns as a large economic, moral, political and social force (Doha, 2005).

The stage is set for SSC, but certain points should be kept in mind while taking the SSC front forward, including the following:

- Making use of the experience gathered from the inter-governmental decisions of the past 25 years and converting them into sound partnerships to obtain tangible results on the cooperation and development front.
- A complementary collaboration could be set up with developing countries having sound economic and developmental background on one side and other countries keen on overcoming the barriers to their progress on the other side in order to achieve mutual benefits.
- Attempts can be made to upgrade temporary and ambitious projects of the past to an achievable level.
- A key role can be played by the UN in helping the developing countries to harbour an environment of cooperation and mutual understanding to achieve their developmental goals.

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Note 3

Climate Change and Health in Africa: Incidence of vector-borne diseases and HIV/AIDS

Note 3. Climate Change and Health in Africa: Incidence of vector-borne diseases and HIV/AIDS

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Global environmental changes such as climate change, ozone depletion, loss of forestry and biodiversity, land degradation and desertification, depletion of water resources, and migration, impact human health simultaneously and interactively. Human health and well-being are dependent on the continued resilience and robustness of the Earth's ecological and biophysical systems. The global climate system, which is an integral component of the Earth's life-supporting infrastructure, is coming under stress from increasing human population, energy and food production. The ensuing climate change is likely to have deleterious effects on human health, and will adversely impact natural systems, infrastructure and economies.

Concern for human health and well-being is one of the compelling reasons to research the effects of global climate change. Health is a focus that reflects the combined effects of climate change on the physical, economic, social and environmental realms. "We have evidence to state that climate change-by altering weather patterns and by disturbing life-supporting natural systems and processes – affects the health of human populations. There are many effects of these changes. And there is still discussion on the exact causality between human behaviour and climate change. But we know enough to take this very seriously and we have every reason to be concerned about adverse consequences for human health" Gro Harlem Brundtland[1]

The impact of climate change on human health has received increasing recognition since it was first mentioned in the IPCC (Intergovernmental Report on Climate Change) FAR (First Assessment Report). The SAR (Second Assessment Report) dedicated a chapter to health (McMicheal et al., 2003). The WHO, WMO (World Meteorological Organisation) and UNEP (United Nations Environment Programme) convened a Task Group to undertake the first comprehensive assessment of the health impacts of climate change (WHO/WMO/UNEP, 1996). The IPCC TAR (Third Assessment Report), acknowledges the fact that human population health is influenced by "upstream" environmental and social conditions (IPCC, 2001). There is now a plethora of research and policy activity regarding climate-sensitive diseases, particularly malaria, dengue, diarrhoeal diseases and under-nutrition. Currently, tuberculosis, HIV/AIDS and malaria dominate health and development policy on infectious diseases. There is an increasing cognisance of the need to place health issues within the sustainable development framework. Health "adaptation" should be integrated into development policies designed to protect and manage the environment and promote socio-economic development and institutional change directed towards assuaging impacts of current climate variability and climatic extremes.

This note explores the nexus between climate change and human health in Africa, with special reference to vector-borne diseases and HIV/AIDS. The cases of East Africa (Kenya) and Southern Africa are elucidated. It is now widely accepted that what makes climate change a particularly vexing problem is that there is an international asymmetry in the genesis of the problem (historical emissions of developed nations) and the locus of potentially devastating impacts (developing nations). These nations have contributed the least to the problem, are hit the hardest, and are least able to cope with the impact.

[1] Speech at Geneva, World Meteorological Day, 23rd March 1999, quoted in Reid, H., Murray, L., and Kovats, S., 2005, Climate Change and Development, Consultation on Key Researchable Issues, IIED.

Current Greenhouse Gas (GHG) emissions from Africa are of little importance on a global scale and have contributed only a negligible share to the accrual of GHGs. However, Africa is particularly vulnerable and its critical challenge to climate change arises when non-climatic threats, such as high population growth, poverty, poor health, HIV/AIDS, lack of access to resources and services, interact and merge with climatic threats, exacerbating natural and human system's vulnerability to climate change.

Climate-induced changes on human health

The WHO defines health as, "the state of complete physical, mental and social well-being and not merely the absence of disease and infirmity" (Kovats et al., 2000:8). Population health is not merely the sum of the personal health of its members, but incorporates concepts of socially determined conditions such as housing, sanitation, literacy, environmental quality and social capital. The contours of health vary across and within nations and regions. Non-communicable disease (cancer, cardiovascular) are predominant in developed countries. In poorer nations, infectious diseases remain important, even as non-communicable diseases are on the rise, due to changes in environment, occupational exposures and lifestyles[2]. Hence these nations face a double burden of escalating infectious and non-communicable diseases. Likewise, there has been a paradigm shift in the perception of environmental risk and health. Conventionally, this referred to risks vis-à-vis exposure to physical and chemical agents, unsafe water and food, inadequate sanitation, poor housing etc. The spectrum of environmental health and risk now embraces adverse effects on human health caused by 'global' environmental changes, human demographics, migration and behaviour.

Impact assessment of climate change must take into account vulnerability of populations to specific health outcomes. Vulnerability is a function of, first, the extent to which a particular health outcome is sensitive to climate change, and second, the population's ability to adapt to the new climatic conditions the vulnerability of a population depends on factors such as population density, dependence on natural resource base, access to resources, level of economic development, income level and distribution, local environmental conditions, institutional and governance structures, social capital, pre-existing health status and quality and availability of public health care.

Understanding of the impacts of climate variability and change on health has increased considerably over the years. However, several fundamental issues complicate this task:

1. Climatic influences on health are often modulated by myriad and complex ecological processes, socioeconomic, adaptive conditions.
2. Inherent uncertainty in the physical and biological processes by which climate impacts health.
3. Climate change one of the coexistent global environmental change affecting human health. For example, transmission of vector-borne disease is jointly affected by climatic conditions, population movement, local environmental conditions, land-use patterns, etc (Woordward, 2000).
4. Diversity in type of disease: chronic, infectious, physical injury, mental health disorders.
5. The long time span of climate change and the wide geographical scale of the area under consideration.

Impacts of climate change on human health can be broadly divided into two:

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[2] Changing pattern of diseases congruent with development is referred to as 'epidemiological transition'.

Exposure to extreme weather events/natural disasters: Major impacts of climate change on human health are likely to occur via changes in magnitude and frequency of extreme events. Heatwaves are associated with exhaustion, heat stroke and with mortality. Disasters occur when climate hazards and population vulnerability converge. A few regions of the world – tropical Asia, tropical America and Africa, and a few areas such as hill-slopes, floodplains, coastal regions, dry land regions - are more vulnerable. Health impacts of floods are classified as immediate (death/injury), medium (spread of communicable diseases – cholera, hepatitis A, etc) and long-term problems (psychological problems). Health impacts of droughts are primarily associated with malnutrition springing from food shortages. However, paucity of water also implies lack of water availability for hygiene, increasing the risk of diarrhoeal disease and water-washed diseases (e.g., trachoma, scabies). In addition to hostile environmental conditions, political, economic and social networks may also break, affecting food distribution and marketing, which may trigger conflict and breakdown in the law and order situation.

Infectious diseases and ecological disruption (agriculture, water resources): Insect or tick vectors transmit many important diseases, such as malaria, dengue, yellow fever, encephalitis, Sleeping Sickness. Since these organisms are sensitive to temperature, humidity, and rainfall patterns, they are responsive to climate change. The potential impacts of sea-level rise on coastal populations include mass migration and impending health problems (spread of vector-borne disease) associated with poor hygienic conditions in refugee camps and psychological stress. Also, there are problems such as salinisation and contamination of freshwater supplies, reduced food production along the coast. Impacts on agriculture could include geographical shifts and yield changes, reduced water for irrigation and potential risks of pests and pathogens. The impending food insecurity can lead to malnutrition, which increases vulnerability to infection. Determining the potential impacts of climate change on water resources is problematic since access to clean water is moulded by socio-economic factors. However, increase in water stress can lead to the use of poorer sources of water, lower efficiency of local sewerage supplies and greater proliferation of pathogens in raw water supplies.

Case of vector-borne disease and HIV/AIDS

The IPCC Special Report on Regional Impacts of Climate Change (IPCC, 1998) acknowledges that climate will have an impact on vector-borne diseases. Changes in climate that can affect potential geographical distribution and transmission of vector-borne infectious diseases include temperature, humidity, rainfall, soil moisture and rising sea level. Determining how these factors can affect their risk is complex, and involves several demographic and societal factors as well.

On the other hand, identifying the interrelations between climate and HIV/AIDS seem far-fetched, at first glance. However, chronically poor environmental conditions (environmental degradation) or environmental stress (extreme climate events) can create conditions germane to the development and spread of infectious diseases, through migration, food shortages, and most relevant for the case of HIV/AIDS, forcing people to indulge in activities/behaviours for survival that they would have otherwise not have engaged in.

Impacts of climate change on Africa: an overview

Africa experienced huge shifts in climate over the past millennia, but likely changes in the next few decades may present some of the greatest challenges (Toulmin, 2005: 12). Historical climate record shows a warming of approximately 0.7 °C over most part of the continent during the 20th century; a decrease in rainfall over large parts of the Sahel, and an increase in rainfall in east and central Africa.

According to the IPCC TAR (2001), potential climate changes in Africa would be as follows:

- Increase in global mean temperatures between 1.5°C and 6°C by 2100.
- Scenarios indicate future warming across the continent ranging from 0.2°C per decade to more than 0.5°C per decade. Warming expected to be greatest over semi-arid regions of the Sahara and central and South Africa.
- Sea levels are projected to rise by 15-95 cm by 2100.
- Varying precipitation: Southern Africa will become hotter and drier, while Central Africa is expected to become hotter and wetter. Some of the drylands may get higher rainfall, but in the form of heavier torrential rainfall.
- Increasing probability of occurrence of extreme weather events: droughts, floods, typhoons etc.

Assessments (Hulme, 1996; IPCC, 1998) conclude that Africa is particularly vulnerable to the impacts of climate change, because of its features relating to a deteriorating ecological base, widespread poverty, inequitable land distribution, high dependence on natural resource base and ravages of HIV/AIDS. The country is hence grappling with several critical issues of development that require urgent attention. Achieving poverty reduction and sustained economic growth remains the key challenge. It is becoming increasingly clear now that the realisation of the Millennium Development Goals can be seriously hampered in Africa with climate change in action.

The main background features to be kept in mind while assessing the vulnerability of the African region to climate change are as follows:

- Diversity: climate, landform, biota, economic and social conditions
- Climate: predominantly tropical, hot and dry. Small regions of temperate climates in the extreme south, north and in high altitudes. Parts of West Africa, as well as western part of central Africa are humid through the year. Most of the human population resides in the sub-humid and semi-arid zones.
- Development status: contains the poorest and least-developed nations of the world. Per capita GDP, life expectancy, infant mortality, literacy are the bottom quartile globally.
- High dependence on natural resource base.
- Governance structures: capacity of African governments to respond proactively to changes.
- Armed conflict.
- Terms of trade and aid dependence.

Climate change and vector-borne diseases

Studies of disease variations associated with inter-annual climate variability (such as those associated with the El Niño cycle) have provided insights into the sensitivity of diseases to climate (McMicheal et al., 2003). This section examines changes in the incidence of malaria in Kenya.

Infectious diseases and climate change: associated linkages

The ecology and transmission of infectious diseases are likely to undergo changes with climate change. These variations are unique for each disease and locality. While some infectious diseases spread from person to person, others depend on transmission via an intermediate 'vector' organism (e.g., rodent, tick, mosquito).

Box 1: Vector-borne diseases considered to be sensitive to climate change

Vector	**Diseases**
Mosquitoes	Malaria, filariasis, dengue fever, yellow fever, West Nile Fever
Sandflies	Leishmaniasis
Triatomines	Chagas' disease
Ixodes Ticks	Lyme disease, tick-borne encephalitis
Tsetse flies	African trypanosomiasis
Blackflies	Onchocerciasis

Source: WHO, 2003, "Methods of assessing human health vulnerability and public health adaptation to climate change", Geneva: WHO

The infectious disease transmission to humans occurs when humans encroach on the disease cycle or when there is a disruption in the environment, including ecological and meteorological factors (IPCC, 2001).

The resurgence of infectious diseases in the past few decades, including vector-borne diseases, have resulted mainly from demographic and societal factors – population explosion, changes in land-use patterns, irrigation systems, movement of people, etc. It may not be correct to aver that climate change has played a significant role in this resurgence.

It is important to note that vector organisms do not regulate their internal temperatures and hence are sensitive to external temperature and humidity. Changes in climate – temperature[3], humidity, rainfall, sea-level rise - therefore alter the distribution of vector species, increasing or decreasing their ranges depending on whether conditions such as vegetation, water availability, and host are favourable or unfavourable for breeding. Hence the factors that influence the incidence and geographical distribution of vector-borne diseases are complex and numerous, and include a host of demographic, socioeconomic and climatic factors.

There are three categories of research that investigate the relation between climate change and infectious disease transmission: evidence from the past; using early indicators of already emerging infectious diseases; use of predictive models[4]. Making use of these models, researchers state that global climate change may be expected to have the following changes:

- Overall incidence and duration of transmission season in particular sites may vary, and even small changes in seasonality are crucial in this context
- Geographical distribution may vary. Climate-induced changes can cause spread of disease in a previously endemic area and sustainable in previously uncharted territory (WHO, 2003)

Case of Malaria

Malaria is one of the world's most serious and complex health problems and it has now been identified as the disease most likely to be affected by climate change (WHO/WMO/UNEP, 1996). Martens et al. (1999), in their most recent modelling of climate change effect on malaria, indicate that the global population at risk would increase by an extra 260-320 million people in the 2080s. The models also project a wide increase in the seasonal duration and transmission in the current and potential new areas. It is present in 101 countries and an

[3] Temperature can also influences the survival, maturation and reproduction rate of the vector organism.
[4] May be statistical, process-based mathematical or landscape models.

estimated 40% of the total world population resides in areas with malaria. Each year, approximately 400-500 million cases of malaria are reported and it causes more than a million deaths, mostly in children (WHO, 1998). Lindsay and Birley (1996) (in IPCC, 2001), cite several reasons for the resurgence of malaria, including insecticide and drug resistance, and changes in land-use, flagging need for public health infrastructure.

Malaria is caused by four distinct species of plasmodium parasite, transmitted by mosquitoes of the genus Anopheles, which are most abundant in tropical/subtropical regions, although they are also found in limited numbers in temperate climes. Transmission is associated with changes in temperature, rainfall, humidity as well as level of immunity. Very high temperatures are lethal for the parasite. In areas where the annual mean temperature, is close to the tolerance limit of the parasite, a small temperature increase would be lethal for the parasite. However, at low temperatures, a small increase in temperature can greatly increase the risk of malaria. Hence, the areas most susceptible to malaria are those at the fringes of its current distribution such as central Asia and Eastern Europe. In this context, climate change is unlikely to affect overall mortality and morbidity in tropical Africa as environmental conditions are already favourable for its transmission. The vulnerable areas are those where transmission is currently limited, mainly by highland temperatures, such as in East Africa (Kenya highlands, for example).

Case Study in Kenya: Incidence of Malaria

Africa has several climate-sensitive diseases, the most prominent being malaria, meningitis and cholera. In recent years it has become clear that climate change will have direct and indirect impacts on diseases endemic in Africa. Malaria epidemics in the past 15 years have been mainly associated with the highlands of East Africa, Rwanda and Zimbabwe closely associated with the inter-annual climate variability.

An increasing array of literature provides evidence on the linkages that exist between weather disturbances and human health primarily through natural disasters and outbreaks of infectious disease. The impact on malaria is because weather disturbances influence vector breeding sites, and hence the transmission potential of the disease.

Although the principal causes of malaria epidemics in the African highlands still are subject of debate, there is increasing evidence that climate plays a significant role.

Kenya is located in East Africa, bordering the Indian Ocean, between Somalia and Tanzania, with Uganda to the west and Ethiopia to the north. The climate varies from tropical along the coast to arid in the interior parts of the country. Low plains rise to central highlands (highest point being Mt. Kenya at 5199 m), bisected by the Great Rift Valley, with fertile plateaus in the west. The Kenyan highlands comprise one of the most successful agricultural production systems. Of the total land, only 8% is arable, 1% is under permanent crops, 37% under permanent pastures, and 30% under forest and woodlands. The country is prone to recurrent droughts in the northern and eastern parts of the region and flooding during rainy seasons. Malaria transmission has been associated with anomalies of maximum temperature in the Kenyan Highlands (Githeko and Ndegwa, 2001). Several studies of long-term trends in malaria incidence, have however not found a link to temperature trends, emphasising instead the importance of other socio-economic, and demographic factors. Hence the nexus remains tenuous, due to paucity of long-term disease data and climate data, and also because of the difficulty involved in controlling for other factors and biological data.

Recent analysis of the climatology of Eastern Africa, reveal that the region is likely to experience heightened temperatures and increased rainfall, which is likely to increase malaria incidence in the region (IPCC, 2001). That malaria is sensitive to temperature in highland regions is illustrated by the effect of El Niño.

(a) Western Highlands of Kenya (West Pokot region), with over 18,000 cases reported several hundred deaths. Outbreak attributed to preconditions of famine and heavy rains.

(b) Northeast Kenya: outbreak from early January through early February 1998, with thousands of cases and at least 1500 reported fatalities. Hardest hit district was Wajir, but events occurred over a several northeastern districts – Garissa, Muhoroni, Mandera, Marsabit, Samburu, Lamu and Tana River districts. Attributed to heavy rainfall that began in October and lasted weeks – accompanied by flooding and severe shortages of water, food, medical personnel and supplies.

Climate Change and HIV/AIDS

The current plethora of literature on climate change impacts has so far very little mention of HIV/AIDS. HIV/AIDS is a colossal development challenge of global proportions facing human societies. Its impacts on both national and household economies have compounded challenges surrounding poverty, inequality and governance. Sixty five percent of the 40.3 million people infected with HIV/AIDS live in Africa, and the worst affected region is Sub-Saharan Africa[5], where there are an estimated 25.8 million people living with HIV, with approximately 3.1 million new infections occurring during the year 2004, claiming the lives of an estimated 2.4 million people.

Within the Sub-Saharan region, the Southern countries are worst affected[6]. In South Africa and Zambia, about 20% of adult population[7] are affected. The four countries where the HIV prevalence rate has exceeded 24% are: Botswana – 38.8%, Swaziland – 33.4%, Lesotho – 31.0%, Zimbabwe- 33.7%.

In West Africa and Central Africa, the disease is relatively less prevalent. Countries where the more than 5% of the adult population are affected include Cameroon – 6.9%[8], Central African Republic – 13.5%, Cote d'Ivorie – 7.0%, Nigeria – 5.4%. In Eastern Africa, prevalence rates range between 2.7% in Eritrea to 8.8% in Tanzania. North Africa is the least affected (51,000 people affected including the Middle East), with Sudan being the only exception.

The epidemiology of AIDS is concerned with the rapid spread of HIV. Almost all experts agree that the vast majority of HIV infections in Africa are a result of unprotected sex and not through unsafe injections (this contributes only 2.5% of the total HIV/AIDS cases in Sub-Saharan Africa)[9]. Although HIV/AIDS is a medical condition restricted to a few modes of transmission, the political economy creates an environment that induces transmission (Webb, 1997).

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[5] www.avert.org/worldstats.htm

[6] Southern Africa is variously defined. For the purpose of this report, it comprises Angola, Botswana, DRC, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.

[7] The percentage of adult population living with HIV, measures the overall state of an epidemic in a country.

[8] For example, sharp increases were witnessed in the incidence of HIV among pregnant women in Cameroon (more than double, to over 11% among those aged between 20-24 between 1998-00).

[9] Expert group stresses that unsafe sex is primary mode of transmission of HIV in Africa, WHO, 14th March 2003.

The reasons why the highest rates of HIV/AIDS prevalence occur in Africa are unclear. Several theories have been propounded – some based on biological explanations and some based on social explanations. The latter emphasises the importance of macro issues – economic, social and political processes, such as poverty and economic marginalisation, social instability, gender inequality, patterns of sexual networking and other STDs (Sexually Transmitted Diseases) that facilitate HIV, rapid urbanisation and modernisation, mobility, debt crisis, government policy, and armed conflict. Hence, individual human behaviour is partially determined by global economic and political structures that act on a local, regional, national and international level (Webb, 1997).

This section explores the nexus between environmental (climate change) processes, migration/mobility and the incidence of HIV/AIDS in Africa with a special focus on Southern Africa. The epidemiology of HIV/AIDS is closely linked to migration/ mobility and the social economy of migration comprises of a set of complex and interrelated factors that can help in explaining the spread of the disease. This section highlights how climate variability/ change acts as a motor for mobility helping in the spread of the virus.

Migration and HIV/AIDS nexus

Migration has been a catalyst in the rapid spread of HIV. Decosas (1996) and Anarfi (1993), state that diseases that are transmitted from person to person will follow the movement of people, and hence the spread of HIV/AIDS is likely to be accelerated in a situation of large-scale migration. Migration is usually defined as the movement of people from one place to another temporarily, seasonally or permanently, for a host of voluntary or involuntary reasons. This definition includes refugees and internally displaced persons (UNAIDS, 2001). In southern Africa, due to the seasonal or temporary character of migration, migrants retune home to their families on a regular basis, facilitating the rapid spread of the disease (Fages, 1999). Migration flows in this region have been mainly reported due to large-scale non-voluntary migration.

Box 2: Links between migration and HIV/AIDS

- High vulnerability due to migration
- Marginalised from prevention opportunities and health services
- Health and social services have a difficulty in assessing them; migrants live in legal limbo, having no stay of work permit, in constant fear of deportation
- Often subjected to compounded forms of discrimination
- HIV/AIDS also a driver of mobility; people migrant to avoid stigma, avail of (better) health services.

Climate as a factor of mobility

What needs to be explored is how climate is a factor for mobility. At the outset, differentiating between population movements triggered by environmental factors and those attributable to socio-politico-economic causes is difficult. Nevertheless, the following areas can be identified:

- Displacement due to extreme weather events/natural disasters and sea-level rise
- Deteriorating agricultural productivity

The next section focuses on the issue declining agricultural productivity in Southern Africa and how migration is unavoidable when a land can no longer sustain the livelihoods of people.

Case of Southern Africa

There is a cogent and critical two-way relationship between HIV/AIDS and food security. What is also known is that present and future prospects of food security are significant determinants of the impacts of climate change.

The HIV/AIDS pandemic is being driven by the very factors that cause malnutrition: poverty and inequality in access to resources. This hunger/malnutrition being experienced by millions across the region increases the vulnerability to the infection, as people are adopting other coping strategies to survive. These include migration (search for additional sources of income and food), and engaging in hazardous work (women becoming sex workers). These actions facilitate the spread of the infection, especially among women and children. For those already infected with the infection, malnutrition further debilitates the immune system, which makes people more susceptible to malaria, TB and other 'opportunistic' diseases, and leads to a faster progression from HIV to AIDS. Further, people weakened by HIV/AIDS find it harder to access prevention opportunities, food and health services since they face compounded discrimination.

As mentioned earlier, what causes malnutrition is poverty, which is caused by weakening food security. Climate variability and change jeopardises food security by causing possible geographical shifts and yield reductions, decreasing water availability for irrigation and by increasing risks to pests. Agriculture and natural resources provide livelihoods to approximately 70-80% of the people in Sub Saharan Africa (Elasha, 2005). The poorest members of society are those most dependent on agriculture for jobs and income. Crop production and livestock husbandry account for about half of household income (IPCC, 2001). Hence agriculture is not only a vital source of food, but also a prevailing way of life.

However, the agricultural scenario in the region is gloomy, with resource degradation, shrinking of land resources, and unequal access to land. Agriculture and household incomes are characterised by interannual and seasonal variations, with fluctuating incomes. Hence any reduction in food production resulting from climate variability immediately affects farmers and agricultural labourers. Falling incomes and joblessness, food shortages and malnutrition, then drive population mobility, acting as a catalyst to the spread of HIV/AIDS.

Way forward

The linkages between climate change and human health are tenuous. The African climate observing system is urgently in need of improvement. For example, very little is known of the Congo basin, which is the key to a global system. Africa needs to engage more not only in global climate observations and modelling, but in smaller regional modelling that can provide location-specific results. Based on such predictions then, a better mapping of vulnerability can be undertaken – which are the coastal areas likely to suffer from a sea-level rise, what diseases are likely to be more prevalent and where, what crops are likely to face declining yields, etc? The key then is the fortification of adaptation capacities of vulnerable communities, regions, and nations to climate-induced changes in human health. This would involve a fortification of environments, livelihoods and infrastructure.

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Note 4

The climate, development, and poverty nexus in Africa

Note 4. The climate, development, and poverty nexus in Africa

(prepared by Ms Ulka Kelkar, TERI)

This note explores the climate, development, and poverty nexus, and discusses some of the intricacies behind low adaptive capacity in African countries. Recognising that this is a very complex set of issues that is still being researched and understood, the note focuses on three themes:

1. the impact of poverty on vulnerability to climate change;
2. the impact of climate variability on poverty; and
3. the impact of development on adaptive capacity.

In discussing these themes, examples are drawn from countries in the Sahel, eastern Africa, and southern Africa.

Background

The number of extremely poor people in Sub-Saharan Africa has almost doubled since 1981 to 313 million people in 2001 (Figure 1a). Africa was also the only continent where the average daily income or consumption of those living on less than $1 a day fell during this period (Figure 1b).

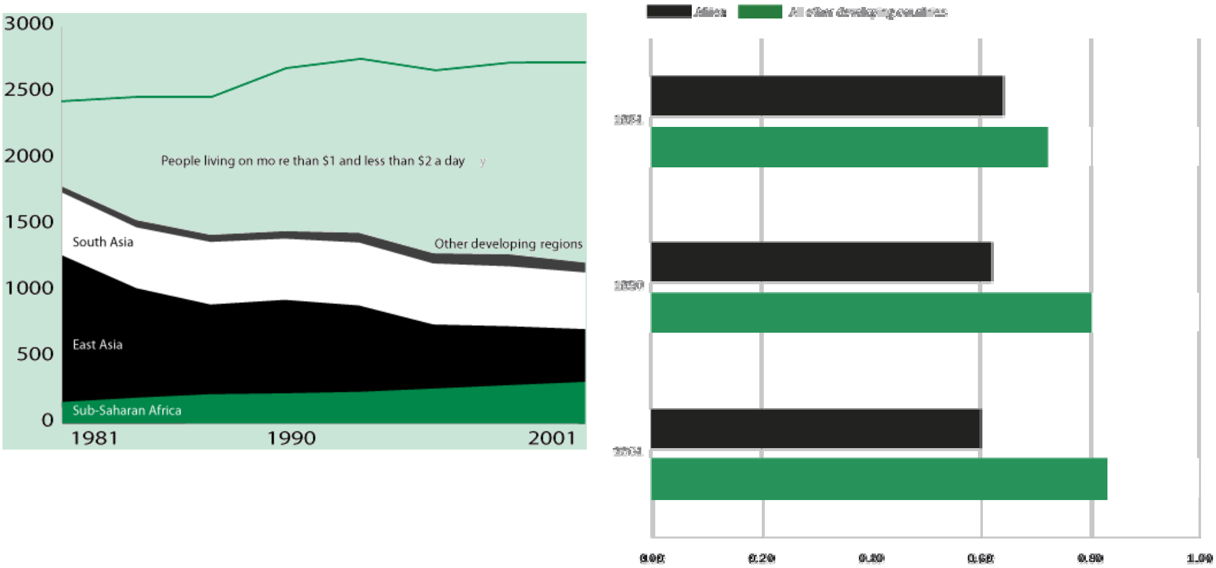


Figure 1 (a) Population living on less than $1 a day (billions) **(b)** Average daily income of the extreme poor (1993 PPP$) Source: WDI (2005)

This negative trend is also reflected in other indicators of poverty, such as the prevalence of undernourishment (Figure 2) or of malaria. Further, by 2003, 12 million children in sub-Saharan Africa had lost one or both parents to HIV/AIDS. Whether measured in terms of the Human Development Index or the Human Poverty Index, sub-Saharan African countries are clustered at the bottom of the rankings.

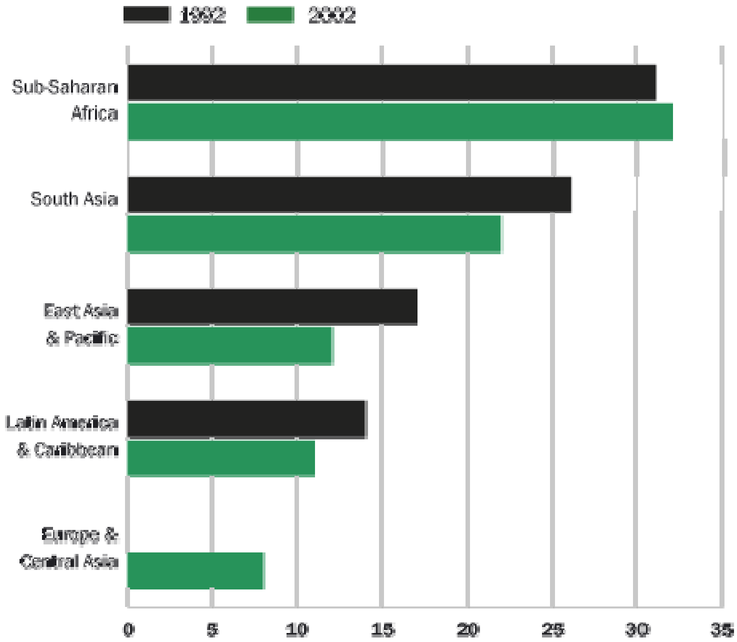


Figure 2 Percentage of undernourished population Source: WDI (2005)

Climate change, by adversely impacting sectors such as agriculture, water resources, and health, presents a formidable challenge for efforts to reduce poverty and achieve the Millennium Development Goals (Figure 3).

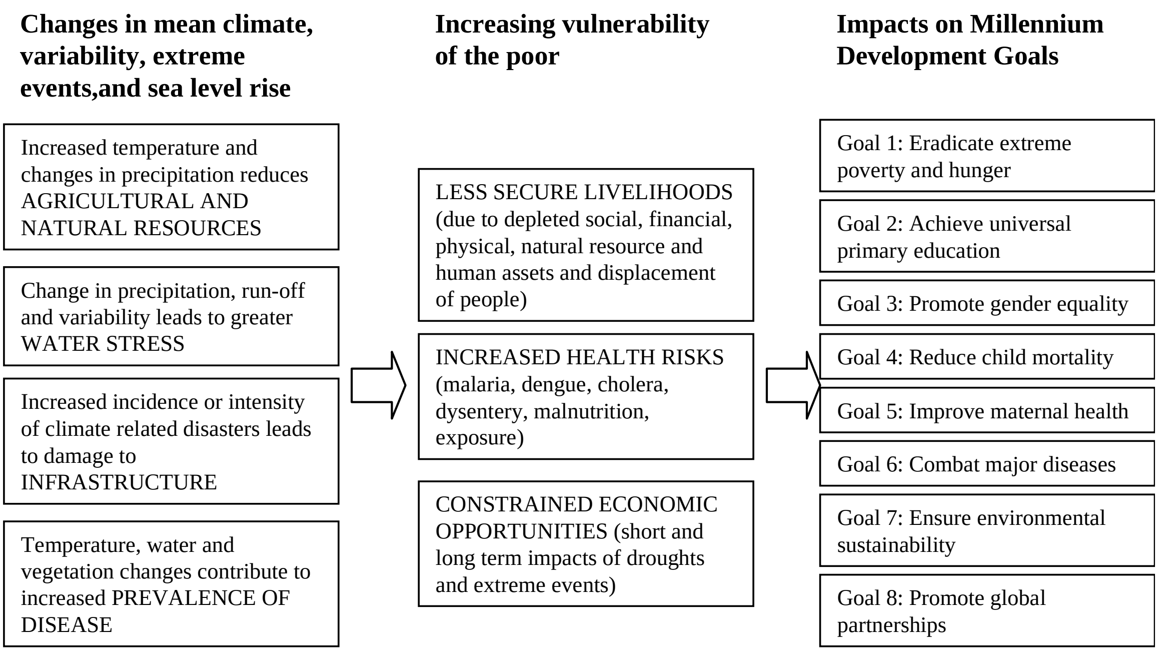


Figure 3 Linkages between the Millennium Development Goals and climate change Source: AfDB et al (2002)

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001) highlighted the following aspects of Africa's vulnerability to climate change:

- Water resources, especially in international shared basins where there is a potential for conflict and a need for regional coordination in water management.
- Food security at risk from declines in agricultural production and uncertain climate.
- Natural resources productivity at risk and biodiversity that might be irreversibly lost.
- Vector- and water-borne diseases, especially in areas with inadequate health infrastructure.
- Coastal zone vulnerable to sea level rise, particularly roads, bridges, buildings, and other infrastructure that is exposed to flooding and other extreme events.
- Exacerbation of desertification by changes in rainfall and intensified land use.

Hence, a two-fold link can be seen between climate change and development. First, the impacts of climate change can severely hamper development efforts in key sectors. For example, increased threat of natural disasters and growing water stress will have to be factored into plans for public health infrastructure. Second, development policies and programmes will themselves influence the ability to adapt to climate change. For example, policies for forest conservation and sustainable energy will, if correctly targeted and implemented, enhance the resilience of communities and thereby reduce the vulnerability of their livelihoods to climate change.

IPCC (2001) summed this up as "activities required for enhancement of adaptive capacity are essentially equivalent to those promoting sustainable development". These can include the following.

- Improved access to resources,
- Reduction of poverty,
- Lowering of inequities in resources and wealth among groups,
- Improved education and information,
- Improved infrastructure,
- Diminished intergenerational inequities,
- Respect for accumulated local experience,
- Moderate long-standing structural inequities,
- Assurance that responses are comprehensive and integrative, not just technical,
- Active participation by concerned parties, especially to ensure that actions match local needs and resources,
- Improved institutional capacity and efficiency.

Key issues

While there is no universally accepted definition of vulnerability, Turner et al. (2003) defined it as the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress. Various factors shape the differences in vulnerability of individuals or groups: entitlements, personal heterogeneity, variations in social obligations, environmental location, livelihood diversification strategies, support networks, empowerment or power relations, and access to knowledge, information, and technology (Noronha, 2003). A combination of factors may increase vulnerability or enhance resilience to stresses (i.e., the capacity to cope or respond to stress in different ways). Within the context of climate studies, the most vulnerable are considered to be those who are most exposed to perturbations, who possess a limited capacity for adaptation, and who are least resilient to recovery (Bohle et al., 1994).

The Africa Environment Outlook described a continuum with the state of vulnerability being characterised by low adaptive capacity, limited choices, and marginalisation, and the state of security being characterized by high adaptive capacity, diverse choices, power, and control (Figure 4).

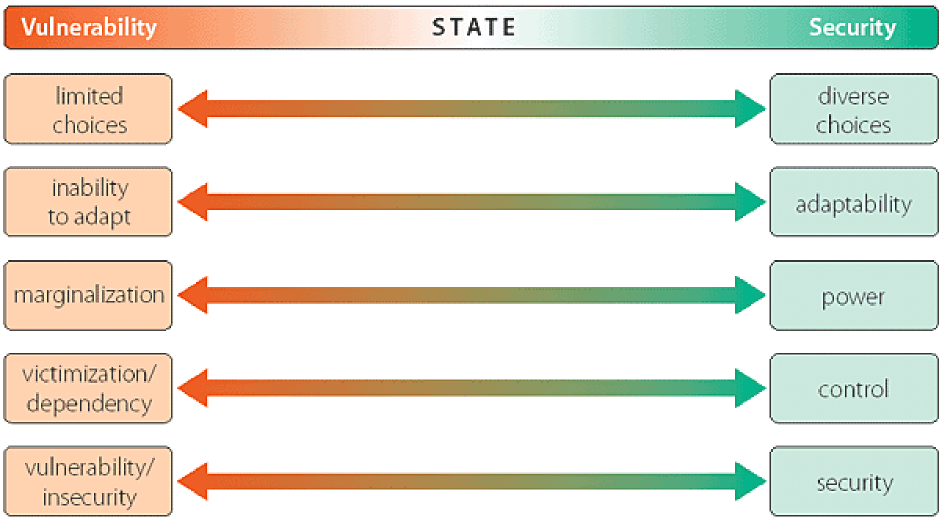


Figure 4 Vulnerability – security continuum. Source: UNEP (2002)

Vulnerability itself is in a process of continual evolution, as the economic, technological, and institutional factors that shape vulnerability are in a state of constant flux (Adger 1999). Coping capabilities can be effective in avoiding a negative outcome of current stresses, but they can also result in reduced vulnerability to future stress. On the other hand, prolonged stress can reduce resilience and increase vulnerability (Noronha 2003).

Poverty increases vulnerability to climate change by reducing options

Poverty was earlier viewed as lack of income, but has been redefined, as reflected in the MDGs, to include lack of access to health, education, and other services, and also to mean powerlessness, isolation, vulnerability, and social exclusion.

Some of the mechanisms through which poverty increases vulnerability to climate change are described below.

The poor are typically forced to live in marginal lands (e.g. flood-prone, degraded soil, etc) and in living conditions which "are predisposing conditions to ill health". This includes low-quality housing (e.g. lack of screen doors), bad sanitation, and unprotected sources of drinking water, which juxtaposed with undernourishment and deficient health care, makes them highly prone to vector- and water-borne diseases.

The poor are highly dependent on subsistence activities involving extraction of natural resources, which are vulnerable to climate change. For instance, in north-west Senegal, human carrying capacity was 13 persons per square km while human population density was 45 persons per square km (IPCC, 2001). People had no option but to cut into their natural resource capital to survive. The result was massive rural exodus, and movement into precarious urban living conditions.

The Senegal Poverty Reduction Strategy Paper highlights the impact of poverty on environmental degradation. “Usually, it is when people, especially the most vulnerable, are caught up in an impoverishment process accelerated by a persistent economic crisis that they become cut off from channels that would enable them to access productive resources. This lack of resources of their own then favors a continual deterioration of their living conditions, aggravates inequalities and, ultimately, leads to extreme poverty, and marginalization” (Republic of Senegal, 2002).

One of the key linkages between poverty and vulnerability is that there is little accumulation of assets to draw on in times of stress. Case studies in Kitui District, Kenya of rural household coping responses to droughts and floods in 1997 and 1999 showed that local agro-ecosystems, in terms of on-farm and off-farm natural resources, played a crucial role. One of the main implications is that the extent of environmental degradation determined many people's livelihood options and ability to adapt to climate change. However, present coping mechanisms may be inadequate in dealing with future changes. Some coping mechanisms, such as over extraction natural resources for food and fuel, may contribute to environmental degradation and potentially limit future resource access and livelihood options (Erikson, 2001).

Climate variability is a fundamental driver of poverty

Through extreme or prolonged stress, climate variability and change can affect the quality, quantity, and reliability of many of the services natural resources provide. This in turn has a critical impact on food intake, health, and livelihoods of poor people. Climate variability can fundamentally drive processes of impoverishment through direct and indirect routes (IRI, 2005):

1. Direct: Severe or repeated climate shocks can push vulnerable households into a persistent poverty trap when their individual coping responses involve divestment of productive assets such as land or livestock.
2. Indirect: Climate uncertainty causes inability to anticipate when climatic extremes will occur, which acts as a disincentive to investment, innovation, and development interventions.

During the period 1991-2000, the occurrence of severe weather disasters gradually increased and the number of Africans who lost their lives as a consequence of severe meteorological and hydrological events almost doubled. Figure 5 illustrates figures for total number of people affected in hydro-meteorological disasters in Kenya, Mozambique, and Senegal. The ENSO floods in 1998 in East Africa resulted in human suffering and deaths, as well as extensive damage to infrastructure and crops in Kenya. Floods in Mozambique in 2000 and in Kenya in 1997-1998 resulted in loss of hundreds of lives, thousands displaced from their homes, and economic losses on more than a billion dollars (OFDA/CRED, 2006; IPCC, 2001).

The prolonged drying trend in the Sahel in the 1970s had a severe impact on nomadic pastoral groups whose scope for migration was constrained by dense occupation of wet areas and failure of permanent water points in dry areas. The result was widespread loss of human life and livestock (IPCC, 2001). The Poverty Reduction Strategy Paper for Senegal also identifies breakdown of natural ecosystems due to the successive droughts of the 1970s as one of the main factors behind the pauperization process (Republic of Senegal, 2002). The USAID Sahel vulnerability assessment for 1999/2000 estimated that 3.8 million people were moderately food insecure in a high-rainfall year. According to the IPCC Third Assessment Report, this could signify chronic vulnerability resulting from structural weaknesses caused by desertification, climate change, and other long-term environmental and socioeconomic phenomena.

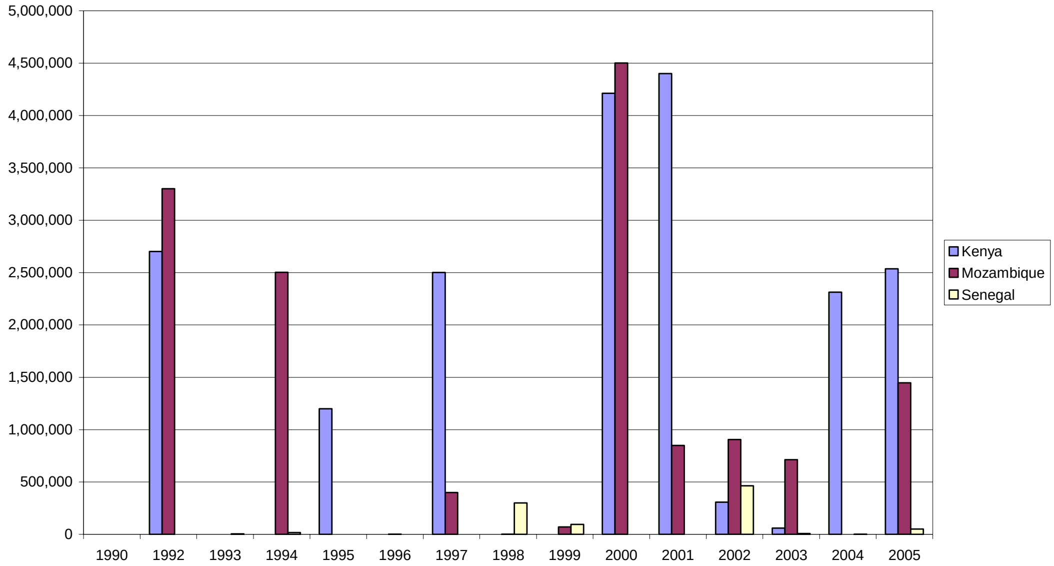


Figure 5 Total affected in hydro-meteorological disasters (1990-2005). Source: OFDA/CRED (2006)

The loss of forest canopy over Kilimanjaro since 1976 has led to average annual reduction of fog water by 20 million cubic metres, or the equivalent of annual drinking water demand of 1 million people living on the mountain. This has serious implications for water shortages in the dry season and the livelihoods of dependent communities (Agrawala et al., 2005).

Finally, recent studies of the potential impacts of climate change on malaria spread in Africa have indicated that by increasing health risks, climate change may deepen poverty traps.

Development choices can lead to maladaptation

Developmental efforts can help build adaptive capacity through two levels of interventions:

1. Climate-specific interventions such as drought proofing, rainwater harvesting, awareness about available drought-resistant varieties, better access to medium- and long-range weather forecasts, and possibly early warning networks.
2. Broader capacity building through education, access to agricultural credit, health care infrastructure, etc.

Conversely, however, inappropriate development policies can possibly lead to maladaptation, by ignoring local needs and priorities, existence of multiple stresses, efficiency in resource use, and principles of good governance. Another issue, particularly relevant for Africa, where many development priorities are determined by donor agencies, is that immediate problems of poverty, erosion, health, and empowerment get emphasised at the expense of longer-term planning e.g. land-use planning (IPCC, 2001). Davison et al. (2003) also made the point that the limited financial resources of governments often preclude re-establishing ecological balance and adopting more rational systems of production and consumption.

One example is poor energy infrastructure in rural areas of sub-Saharan Africa. At present less than 24% of the population has access to electricity, and the World Energy Outlook projects that by 2030, half the population of sub-Saharan Africa will still be without electricity. Despite low rates of electrification, industrialisation, and vehicle ownership, the uncontrolled and inefficient use of traditional biomass for cooking and heating has resulted in an energy intensity higher than the world average (WEO, 2004). This aggravates soil erosion and flooding, leads to reduced fertilizer availability and hence agricultural productivity, and can also create indoor air quality related health problems.

Similarly, rapid population growth, expanding urbanization, and increased economic development have combined to increase water stress in Africa. Figure 6 shows that countries such as Mozambique with 4000 cubic metres water availability per person per year in 1990, are projected to become water stressed (i.e., less than 1700 cubic metres water availability per person per year) by 2025.

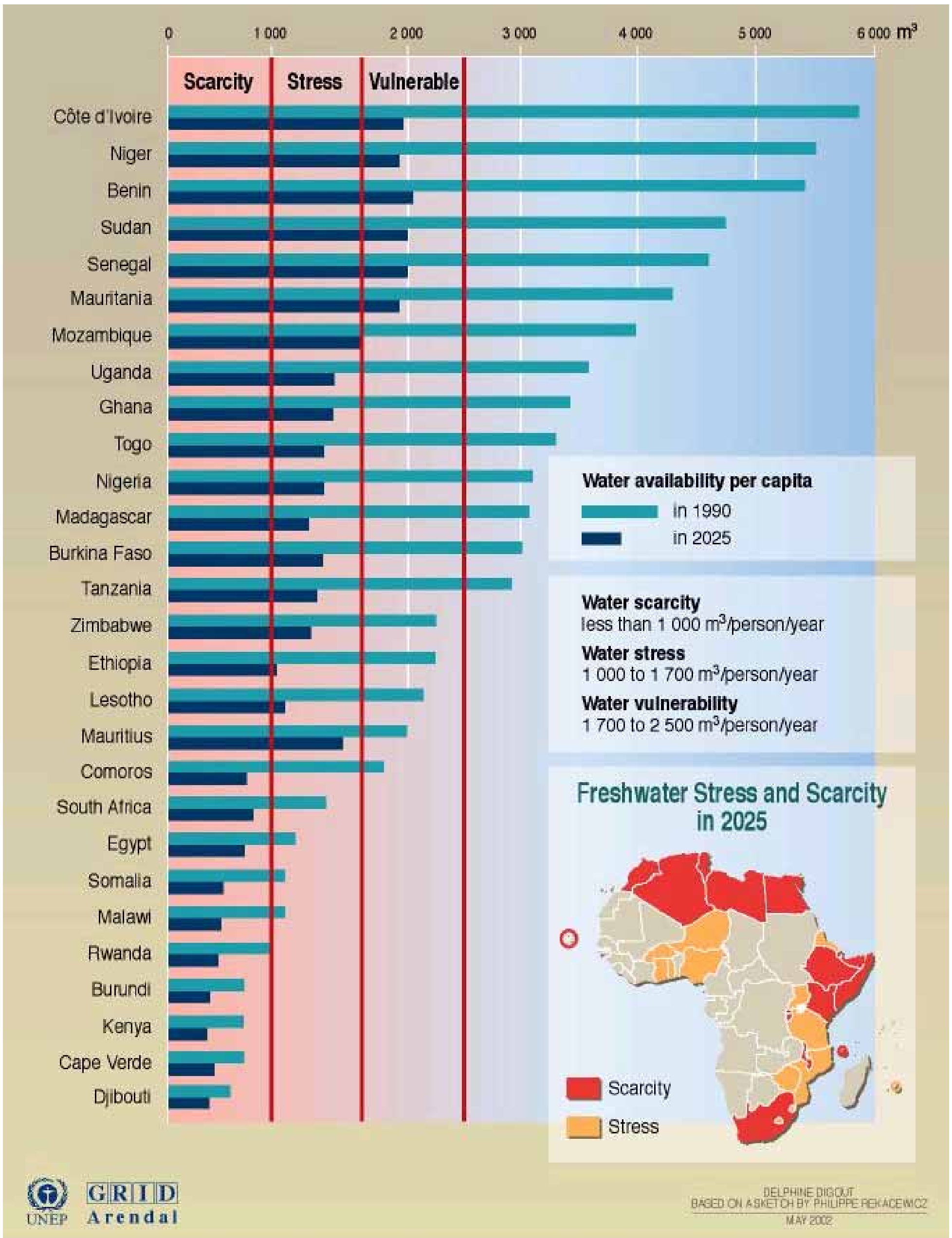
Because of fertile soil, fisheries, and other natural resources, wetlands and floodplains attract dense settlements. They are highly vulnerable to flooding but often lack adequate planning and regulation. This was demonstrated by the floods in coastal areas of central and southern Mozambique in early 2000 and 2001, which caused considerable damage to property, transport infrastructure, and communications.

Agriculture in Africa suffers from declining soil productivity due to deforestation and reduced fallow periods, as well as low purchasing power and access to agricultural inputs. In Kenya, food aid comprised two-thirds of food imports in the 1990s. This dependence on food production makes the country vulnerable to price fluctuations and further exacerbates problems of food insecurity and undernourishment. All these pressures render traditional coping options inadequate. The result is a downward spiral with high levels of migration, increased urbanisation, and mounting pressure on the environment (IPCC, 2001).

The way forward

It has been emphasised that for a number of African countries, adaptation is an option not by choice but by compulsion (AIACC 2004). Clearly the challenge is a complex multifaceted one, so the need to identify some priority areas, and to pool resources and expertise through regional and south-south cooperation. DFID-funded consultations coordinated in eastern and western Africa by the International Institute for Environment and Development revealed the following priority areas:

- Semi-arid lands in Kenya, Sudan, Ethiopia, Eritrea and Tanzania;
- Coastal zones, primarily in Kenya and Tanzania;
- Floodplains in Kenya, Sudan and Uganda;
- Mountainous areas in Kenya, Uganda and Tanzania;
- Semi-arid lands in the Sahelian countries;
- Coastal zones in Senegal and Gambia;
- Floodplains in Gambia and Senegal;



Source: United Nations Economic Commission for Africa (UNECA), Addis Ababa ; Global Environment Outlook 2000 (GEO), UNEP, Earthscan, London, 1999.

Figure 5 Present and future freshwater availability in Africa Source: UNEP/GRID (2002)

Cooperation is needed in research, sharing and transfer of capacities, and joint management of trans-boundary resources. Instead of competition among countries, regional scale programmes could be formulated for flood control, transport, or electricity.

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Note 5

The Sub-Saharan Africa Challenge Programme

Note 5. The Sub-Saharan Africa Challenge Programme

An example of combining spatial analysis with non-spatial, qualitative information in a priority setting process was the selection of pilot learning sites for the sub-Saharan Africa challenge programme (SSA CP). Details of this work can be found in Thornton et al (2006). The SSA CP is designed to address the problems of failures of agricultural markets, inappropriate policies, and natural resource degradation, that contribute to the continuing deterioration of livelihoods and food security in the region. It seeks to do this by redefining the roles of scientists and farmers through collaborative learning processes, addressing questions about the level, timing, type and form of participation, as well as the most effective approaches and methods to foster them. One question that was addressed in designing the initiative was deciding where to work so as to maximise the chances of successful testing of this new approach, so that it would lead to significant reductions of rural poverty. A participatory process was embarked upon to design a framework to accomplish this site selection, and then to apply it in west, east and southern Africa. Various considerations had to be taken into account: sites needed to be selected and problems identified so that new research could add value to past or existing activities; problems and solutions needed to be applicable to much broader areas than the pilot learning sites themselves; and the sites were to serve as "models" that could be quickly replicated and expanded upon in subsequent activities of the challenge programme.

This site selection clearly had social, biophysical, cultural, economic and institutional dimensions, and while some of these dimensions could be represented spatially, many could not. Accordingly, a multi-phase approach was undertaken. SSA was first broken down in terms of length of growing period. Various "filters" were then applied, including human population density (current and future), market access, levels of poverty, and current and likely future stresses to the various systems. The work itself and the choice of filters was carried out by regional teams, who produced a set of up to 12 candidate sites for further consideration. A set of non-spatial criteria were suggested and adapted by the regional teams, against which each site was scored in terms of its suitability (see Table 1).

The final phase in the process was to weigh up all the sites together, and pick three so that the resulting set contained a range of different activities, dealt with different problems, and in general formed a complementary portfolio of activities (Table 2).

Table 1. Non-spatial criteria for assessing candidate research sites

General suitability	Is the candidate site in a conflict area or war zone?
Institutional environment	How strong are the institutions that are working here?
Policy environment	How are the extension services? Are there NGOs and development projects in the area?
Local livelihoods & household options	What crops and livestock are in the area? Are there options for off-farm income?
Critical health issues	Are there serious malaria and HIV/AIDS problems?
Broad poverty trends	Is there depopulation or out-migration? Is poverty increasing or decreasing?
Social capital	Are there self-help community groups? What kind of social networks exist?
Commercial sector linkages	Are smallholders linked to the commercial sector?
Added value	Will new research add value to what's been done before?
Representativeness	Is the site representative of other parts of SSA?
Potential for impact	What are the prospects for research success and impact? Is the work doable?

Table 2. Some characteristics of the three selected sites

	Kano-Katsina-Maradi (Niger, Nigeria)	Lake Kivu (DRC, Rwanda, Uganda)	Zimbabwe-Mozambique-Malawi corridor
LGP (months)	2.5 – 6	> 9	>5 - 10
Annual rainfall (mm)	500-1100	1,500-2,000	700 - 800
Relief	Mostly flat, intersected with inland valleys	Mostly mountainous, 1500-1800 masl	From mountainous (1,000-1,500 m) to flat plains (400-700 m) towards coast
Major NRM issue	Soil nutrients	Vulnerability	Soil fertility management
Pop density km^{-2}	218	779	42
Pop growth rate	2.4 %	2.2 %	1.2 %

Several useful lessons were learned from the process, including the continued need for baseline spatial and non-spatial data to improve the targeting of research in the future that is designed to alleviate poverty in developing countries. The CP is now getting underway at the selected pilot learning sites, and work is in progress to develop and implement an impact assessment framework and system, based around a set of appropriate baseline indicators, that can be used to assess proposed research activities and monitor and evaluate them once the "research for development" activities start.

Note 6

The ASARECA priority setting work

Note 6. The ASARECA priority setting work

ASARECA is a non-political association of directors of research institutes in eastern and central Africa. It serves as a forum for promoting agricultural research and strengthening relations between NARS and the international agricultural research system. Its informal status as an association has provided it with flexibility in adapting to changing circumstances and opportunities. Its mission is to fight poverty, reduce hunger and enhance resources through regional collective action in agricultural research for development. In 2005 ASARECA published a strategic plan for the period 2005-2015 (ASARECA, 2005). The vision of agriculture is one of a flow of products and investments that optimize the contribution of agriculture to growth and the reduction of poverty and hunger on a regional level. ASARECA expects to be a significant player in facilitating innovation and making spillovers happen.

IFPRI and ASARECA worked together to try to answer the question, where to invest resources. Priorities were developed on the basis of development domains, regions defined by agricultural, market and population characteristics that may cut across national boundaries. Eight development domains were defined, based on quantitative measures of agricultural potential, market access and population density. Agricultural potential was based on length of growing period overlaid on soil characteristics. Market access was based on the time of travel to different types of market: purely local markets, regional, major national urban markets, and export points: international port or airport. Population density (above or below 100 km^{-2}) was used as a proxy for demand and land pressure. The assumption is that agricultural strategies are likely to have the same relevance for areas falling in the same development domain.

From the analysis (see Table and Figure), four areas were identified as strategically important for agriculture:

- HLL: The largest agricultural domain accounts for 38 percent of the area in ECA and is found in most countries. It is considered the highest strategic priority because of its size, suitability for different crops, and potential for growth. However, it will require investment in infrastructure, security, and market access to be exploited.
- HHH: This domain has favourable conditions and accounts for less than 2% of the area and already contains 17% of the population and 14% of rural population. Intensification and management-intensive techniques are needed here.

- HLH: A small domain in terms of area with high population density. Being able to exploit high-value products will depend on solving the market access problems. Nevertheless, it remains a small niche.
- LLL: In spite of “low potential”, this domain is important in terms of size and rural population, and is seen as a strategic area for the region.

The implementation of ASARECA’s strategy in the coming years will be designed to address the issues raised by this development domain analysis.

Table 1. Relative importance of the IFPRI-ASARECA development domains - agricultural potential, market access and population density ranked high H or low L (ASARECA, 2005)

Development Domain	Population %	Rural Population %	Area %	Strategic Importance
HHH	17	14	2	Good niche, NRM concerns
HHL	6	5	3	Small, isolated niches
HLH	13	15	3	Small niche with access problems,
HLL	24	28	38	Highest strategic priority
LHH	10.	7	1	Requires irrigation, intensification
LHL	4	3	1	Intensification, irrigation niche
LLH	5	6	1	Low potential high density, emigration
LLL	13	15	21	Important for equity
Not included	8	6	31	Parks, protected areas, isolated

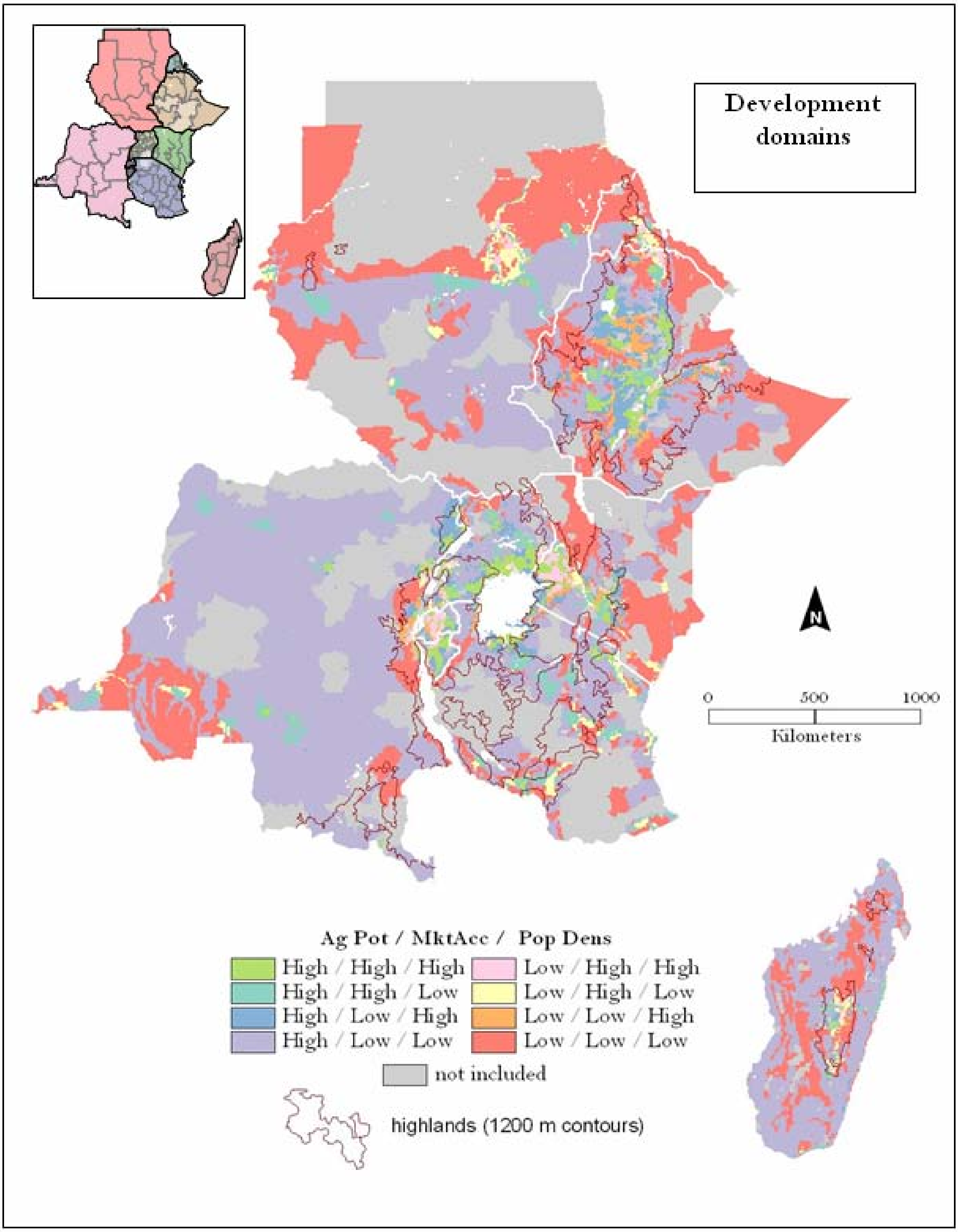


Figure 1. Development domains and administrative boundaries (ASARECA, 2005)

Note 7

The SLP's food-feed impact assessment framework

Note 7. The SLP's food-feed impact assessment framework

The Systemwide Livestock Programme (SLP) of the Consultative Group on International Agricultural Research (CGIAR) is a consortium of 11 international agricultural research centres and the organisations that collaborate with them. The SLP aims to link crop and livestock research efforts internationally to catalyse on-farm benefits for the rural poor. One of the most serious problem faced by poor livestock keepers is the lack of feed for their animals. Few smallholders can afford to take land out of food crop production to grow fodder crops because they are under constant pressure to feed their families. Poorly fed animals are more vulnerable to diseases, cultivate the land less efficiently, produce less milk, meat and manure and have a lower market value. Farmers urgently need crops for both feed and food, but few previous research efforts have considered both requirements. Research supported by the SLP is developing crops such as sorghum and cowpea for dual-purpose use to meet the nutritional needs of both humans and animals.

The mixed crop-livestock systems that are the backbone of agricultural production in the tropics are rapidly changing because of various drivers such as population growth, climate change, and changes in demand for livestock products. A need was identified to help the SLP assess potential impacts of new research projects on livelihoods, using a standardised approach across the CGIAR to impact assessment that is both inclusive and holistic. A framework is being constructed to do this (Herrero et al., 2005), built around the five basic stages in the impact assessment process (Figure 1): the identification of recommendation or development domains (where may the technology be relevant), an assessment of the probability of useful knowledge generation (what sort of research investment may be needed, how long will it take to complete, what are the appropriate delivery pathways, etc), relevant characteristics of the product of the research such as a technology, a tool or methodology, or a policy (is it low cost for the farmer, does it increase labour demands, does it build on a well-known practice or is it new, etc), understanding who is likely to be affected by the changes (apart from producers, are there likely to be impacts on input suppliers and consumers, for example), and estimating what the nature and size of the impacts may be (on production and household income, etc).

The specifications for the impact assessment framework was drawn up at a workshop in mid-2005, and software is being developed to implement it. It contains a set of spatial data layers that the user can select to map out appropriate development domains for the intervention being considered. As a simple example, Figure 2 shows the areas in Kenya that are highly suitable for Pennisetum purpureum (Napier grass), in terms of three constraints: altitudes between 1500 and 2000 m above sea level; rainfall in excess of 750 mm per year, and soil pH greater than 4. The shaded areas are those that satisfy these constraints. It can be seen that this domain contains about 33% of Kenya's human population, but less than 3% of the land area of the country. The software is being tested by SLP research managers, to help them assess and rank proposals for food-feed crop research activities in 2006 and beyond.

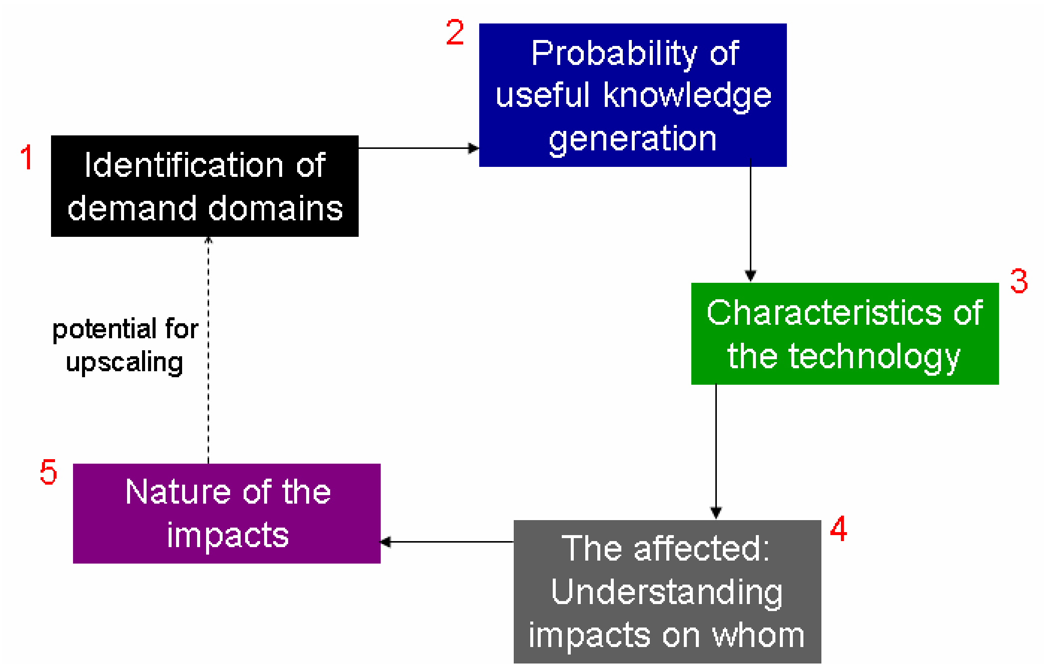


Figure 1. Food-feed research impact assessment as a five-stage process

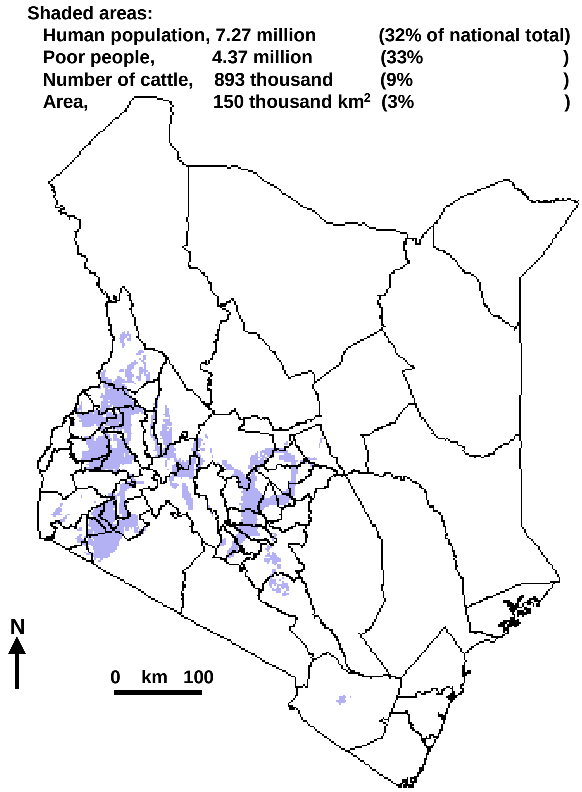


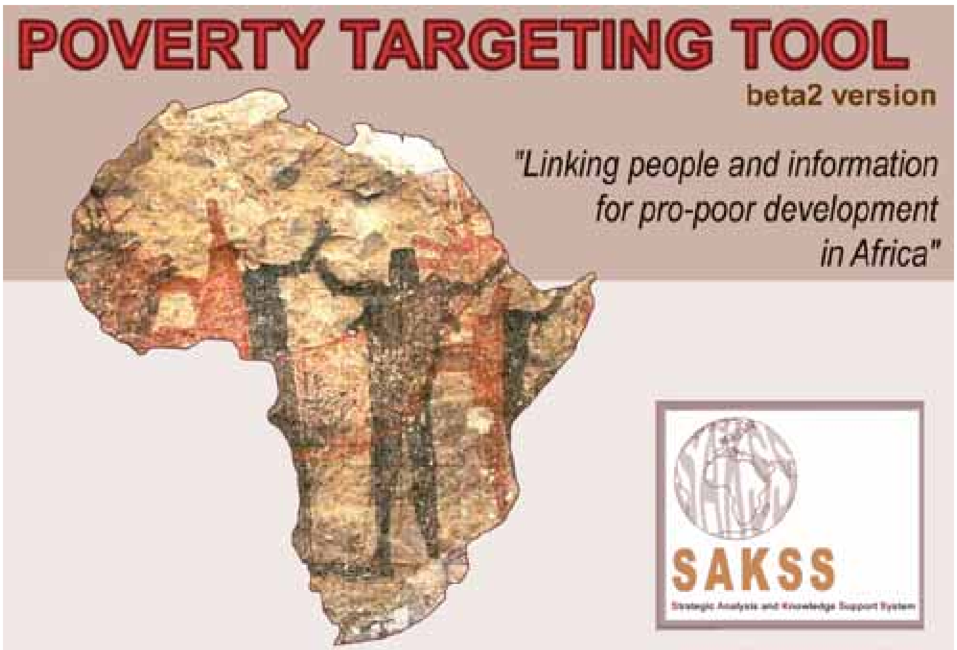
Figure 2. Domains in Kenya with high suitability for Napier grass, defined in terms of altitude, rainfall and soils constraints

Note 8

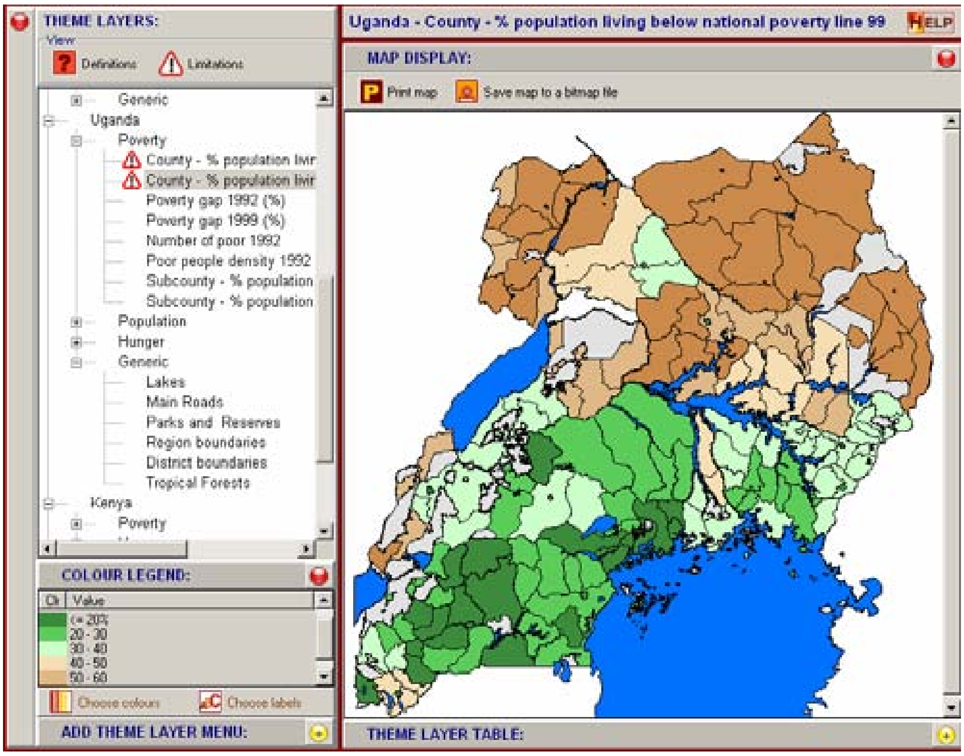
The SAKSS poverty targeting tool

Note 8. The SAKSS poverty targeting tool

As African governments and their partners begin identifying areas for agricultural and rural investment and policy intervention, it is crucial that the links between investments, agricultural growth, and poverty reduction are clearly understood. In response, several development partners are working together to establish a Strategic Analysis and Knowledge Support System (SAKSS). The purpose of SAKSS is to compile, analyze, and disseminate data, information, and tools in order to help inform the design, implementation, and monitoring and evaluation of rural development strategies, with the ultimate aim of making them more effective. The intended users of SAKSS include not only African governments and donors but also local and international research institutes and universities, the private sector, and non-governmental organizations. SAKSS is organized as networks of research and implementation partners linked to the many sources of information, research, and analysis throughout the continent. The vision is for SAKSS to become institutionalized in national and regional nodes within relevant national ministries, planning units, and regional organizations. With the leadership of IFPRI, and in cooperation with NEPAD and the continent's many regional economic organizations, SAKSS regional nodes and networks are now being launched in East, Southern, and West Africa, led by four CGIAR partner centres. At the national level, country SAKSS are currently being piloted in Ethiopia, Uganda, and Ghana (source: http://www.ifpri.org/themes/sakss/sakss.htm).



One tool that is being developed is a poverty targeting tool. This is CD-based, and makes use of the considerable work on poverty mapping carried out in Africa and assembles these data into an easy-to-use mapping and data extraction tool. The poverty CD uses the same basic mapping tool, developed at ILRI, that is in the food-feed impact assessment framework tool (Note 7). The screen below shows 1999 data from Uganda, showing percentage of the population living below the national poverty line. It is envisaged that the poverty targeting tool will be followed by several others, looking at different aspects such as environmental issues and trade and investment data.



Note 9

Simulating regional production with crop models

Note 9. Simulating regional production with crop models

Existing simulation models have been used to estimate regional production under different scenarios of climate change. An example is that of Jones and Thornton (2003), who used the CERES Maize model to simulate the growth, development and yield of the crop. The model runs with a daily time step and requires daily weather data (maximum and minimum temperature, solar radiation, and rainfall). It calculates crop phasic and morphological development using temperature, day length and genetic characteristics. Water and nitrogen balance submodels provide feedback that influences the developmental and growth processes. CERES-Maize has been widely used in Africa, as well as elsewhere. The model needs weather, soil and crop management information to run. For weather, we used a weather generator, MarkSim, and we downscaled outputs from the GCM HadCM2, using similar techniques to those outlined in section 4 of this report. To estimate the likely maize-growing areas in Africa, we eliminated pixels with growing seasons shorter than 60 days and growing season temperatures below 10 ºC, and pixels classified with no or little cultivation from a global land cover database, and pixels in protected areas. We used the FAO digital soils map of the world and classified soils into those with moderate or high agricultural suitability. Using a large soil profile database from the International Soils Reference and Information Center (ISRIC), we defined soil profiles for each soil type for use with the crop model. We estimated planting dates for each pixel-soil type combination using a simple water balance model. The simulated maize crops were sown at planting densities typical of smallholder maize production systems that are hill-planted and rainfed, in the tropics (3.7 plants m^{-2}). We carried out 20 replicates (different weather years) for a number of scenarios, including a baseline that used 1990 climate normals and a “2055” scenario, using climate normals derived for the period 2040-2069 associated with the SRES B2 scenario..

The figure shows mean simulated rainfed maize yields for a window of eastern Africa for current conditions; the middle panel shows the coefficient of variation of maize yield, and the right-hand panel shows the mean yields using the 2055 normals. Comparing the right-hand panel with the left-hand, it can be seen that yields are projected to decrease to 2055 (there is less “green” in the right-hand map). This kind of detailed analysis is being extended to look at other crops (such as beans, which can be expected to be more sensitive to temperature increases than maize) and at livestock productivity impacts, using other crop and livestock models, such as those associated with the International Consortium for Agricultural Systems Applications (ICASA). The results from this work have highlighted the fact the responses to changing climate risk and climate change have to be assessed at high resolutions, as there may be considerable heterogeneity in crop and pasture response to changing weather patterns even over relatively small areas. In addition, household impacts have to be assessed from a systems perspective, as farmers rarely operate only one enterprise, or operate one enterprise in isolation of the other on- and off-farm activities. This suggests the need for household models that are able to assess the impact of changes in crop yields on the farming system as a whole. For example, if maize stover yields decrease along with maize grain yields, and the stover is a key dry-season feeding resource for cattle, are the livestock in some systems going to be suffering feed deficits, and if so, where might extra feed come from. Several different groups are currently working to develop and apply household-level models that are tailored for tropical conditions, and these could ultimately be linked to soils, weather, and systems characterisation databases to enable these more holistic types of impact assessment to be carried out. One example is the systems characterization tool IMPACT (Integrated Modeling Platform for Animal Crop systems) (Herrero et al., 2006). With this tool, systems can be compared across different places, allowing users to assess the impacts of changes in household resources, income, food security, and other indicators of household well-being.

Some households in parts of Africa are already feeling the impacts of climate change as changes in the frequency and severity of extreme events. Risk analysis is important to help households cope, but it has to be beyond exercises in modelling probable outcomes, to include investigations into how farmers perceive risk and how they behave to minimize it. In many parts of SSA, farmers are well used to dealing with drought and its impact, and understanding existing coping mechanisms is crucial if appropriate responses to increasingly variable weather are to be developed.

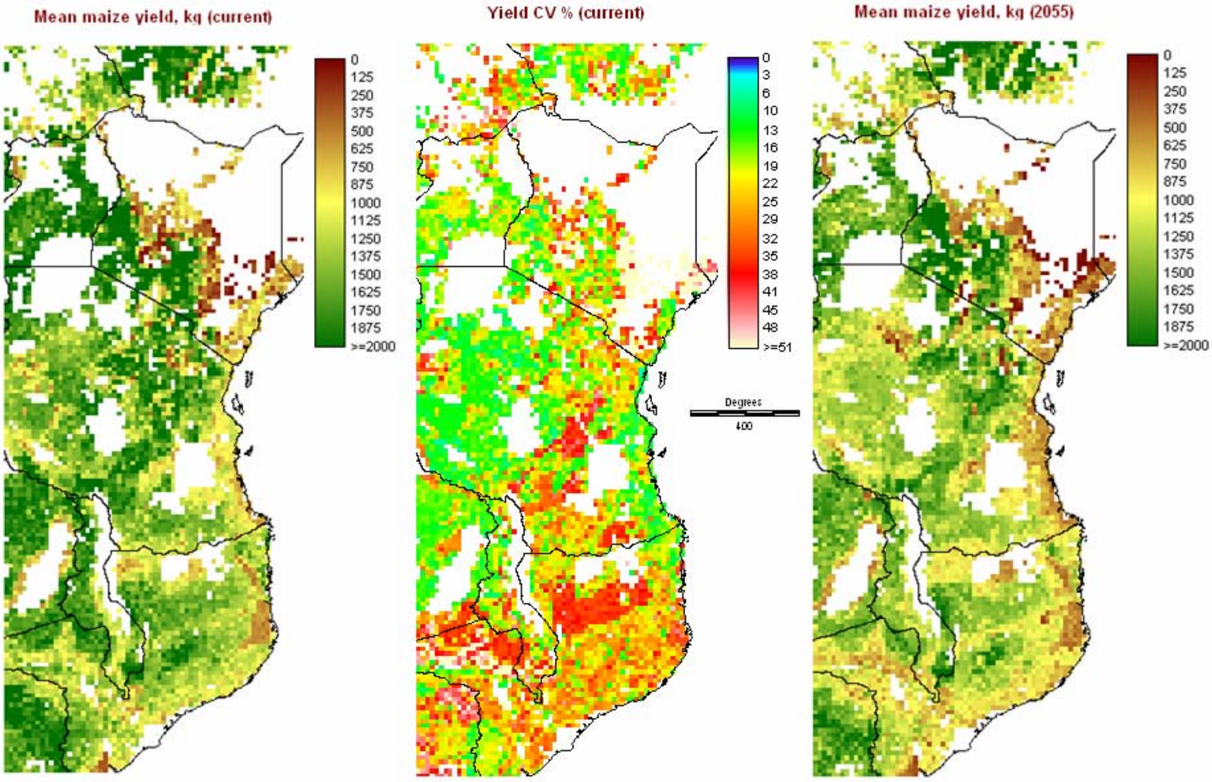
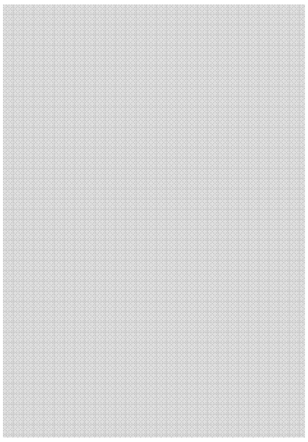
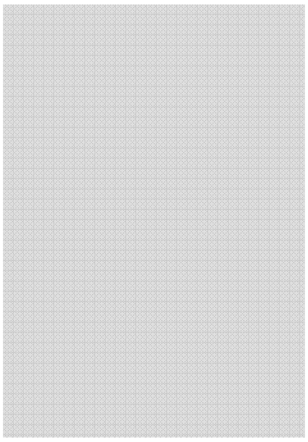
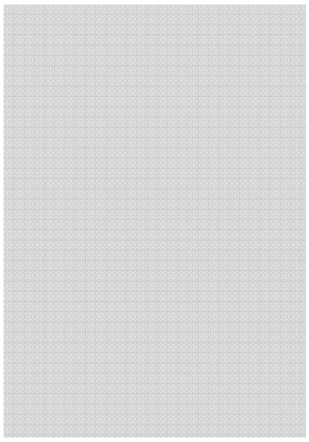
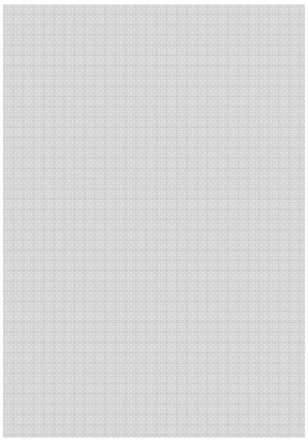


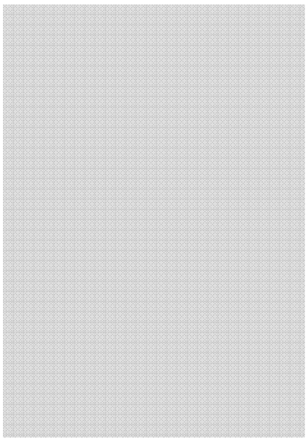
Figure 1. Simulated rain-fed maize yields for part of eastern and southern Africa: mean yields under current conditions (left), the CV of current yields (middle), and mean yields using climate normals for 2055 using downscaled outputs from HadCM2 and the SRES B2 scenario (right) (source: Jones and Thornton, 2003).

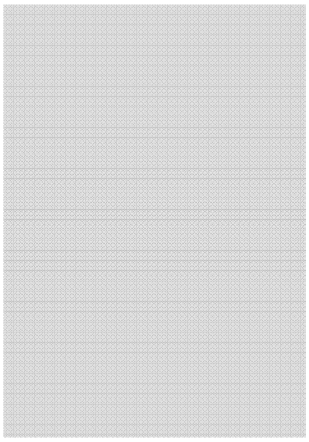


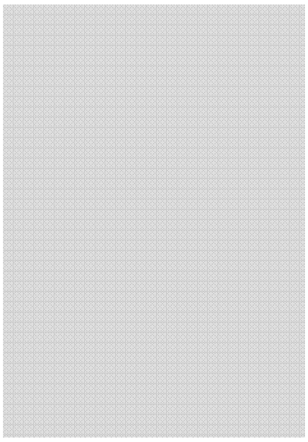


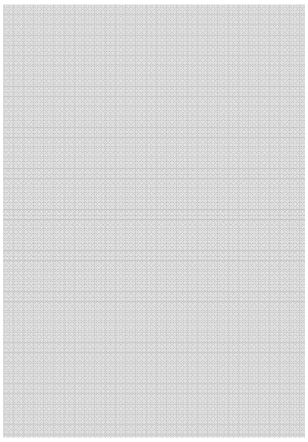


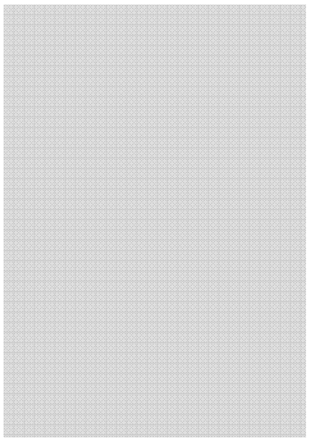












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